CHAPTER 3: ELECTRICAL PRINCIPLES

Unit of learning code: ENG/CU/EI/CC/02/4/A.

Related Unit of Competency in Occupational Standard: **Apply Electrical Principles Skills.**

3.1 Introduction to the unit of learning

This unit describes the competencies required by a technician in order to apply a wide range of Electrical principles in their work. Which includes; Basic Electrical quantities, D.C and A.C circuits in electrical installation, electrical machines, earthing in Electrical installations, capacitance and inductance

3.2 Summary of Learning Outcomes

1. Basic Electrical quantities

2. D.C and A.C circuits in electrical installation

3. Electrical machines

4. Earthing in Electrical installations

5. Capacitance and inductance

3.2.1 Learning Outcome 1: Basic Electrical Quantities

3.2.1.1 Introduction to the learning outcome

To apply basic Electrical quantities correctly one requires the ability to understand the SI units of Electrical quantities. Stated, Calculate and relates the quantities in Ohm’s law.

3.2.1.2 Performance Standard.

- Basic SI units in Electrical are identified as established standards.
- Quantities of Charge, force, work and power are identified as per established standards.
- Perform calculations involving electrical quantities i.e., Current, Resistance and voltage as per established standards.

3.2.1.3 Information Sheet

Definition of terms.

SI unit

The system of units used in engineering and science is the Système Internationale d'Unités (International system of units), usually abbreviated to SI units, and is based on the metric system. This was introduced in 1960 and is now adopted by the majority of countries as the official system of measurement.

Quantity Unit

Length metre, m

Mass kilogram, kg

Time second, s

Electric current ampere, A

Thermodynamic temperature kelvin, K

Luminous intensity candela, cd

Amount of substance mole,

Charge

The unit of charge is the coulomb∗ (C), where one coulomb is one ampere second (1coulomb = 6.24×1018 electrons). The coulomb is defined as the quantity of electricity which flows past a given point in an electric which flows past a given point in an electric circuit when a current of one ampere∗ is maintained for one second. Thus, charge, in coulombs $Q = It$ where I is the current in amperes and t is the time in seconds

Force

The unit of force is the newton∗ (N), where one newton is one-kilogram meters per second squared. The newton is defined as the force which, when applied to a mass of one kilogram, gives I t an acceleration of one meter per second squared. Thus force, newton's, $F=ma$ where m is the mass in kilograms and a is the acceleration in meters per second squared. Gravitational force or weight is mg, where g = 9.81 m/s2.

Work

The unit of work or energy is the joule∗ (J), where one joule is one newton meter. The joule is defined as the work done or energy transferred when a force of one newton is exerted through a distance of one metre in the direction of the force. Thus, work done on a body, in joules, $W=Fs$ Where F is the force in newton's and s is the distance in metres moved by the body in the direction of the force. Energy is the capacity for doing work.

Power

The unit of power is the watt∗ (W), where one watt is one joule per second. Power is defined as the rate of doing work or transferring energy. Thus, power, in watts $P= Wt$ Where W is the work done or energy transferred, in joules, and t is the time, in seconds. Thus, energy, in joules $W =Pt$.

Resistance and conductance

The unit of electric resistance is the ohm (Ω), where one ohm is one volt per ampere. It is defined as the resistance between two points in a conductor when a constant electric potential of one volt applied at the two points produces a current flow of one ampere in the conductor. Thus, resistance, in ohms $R= VI$ where V is the potential difference across the two points, in volts, and I is the current flowing between the two points, in amperes. The reciprocal of resistance is called conductance and is measured in Siemens (S), named after the German inventor and industrialist Ernst Siemen∗ conductance, in Siemens $G=1R$ where R is the resistance in ohms.

Electrical power and energy

When a direct current of I amperes is flowing in an electric circuit and the voltage across the circuit is V volts, the power, in watts $P=VI$

Electrical energy =Power×time

=VIt joules

Although the unit of energy is the joule, when dealing with large amounts of energy, the unit used is the kilowatt hour (kWh) where

1 kWh = 1000 watt hour

= 1000× 3600 watt seconds or joules

= 3 600 000 J

1.2.1.4 Learning Activities.

1. Identified basic SI units in Electrical as per established standards

2. Identified quantities of charge, force, work and power as per established standards

3. Performed calculations involving Electrical quantities i.e resistance, current and voltage as per established standards.

1.2.1.5 Self-Assessment

1. If a current of 5A flows for 2 minutes, find the quantity of electricity transferred.

2. Find the force acting vertically downwards on a mass of 200 g attached to a wire

3. A portable machine requires a force of 200 N to move it. How much work is done if the Machine is moved 20 m and what average power is utilized if the movement takes 25 s?

4.: A source e.m.f. of 5V supplies a current of 3A for 10 minutes. How much energy is Provided in this time?

5. What is a derived unit?

6. A mass of 1000 kg is raised through a height of 10 m in 20 s. What is

(a) the work done and (b) the power developed?

1.2.1.6 Tools, Equipment, Supplies and Materials

- Scientific Calculators
- Ohmmeter
- Voltmeter
- Ammeter

1.2.1.7 References

- John Bird (2017) Electrical and Electronics Principles Technology fifth Edition
- John Bird(2017) Electrical and Electronics Principles Technology sixth Edition

1.2.1.8 Responses to Self-Assessment

Problem 1. If a current of 5 A flows for 2 minutes, find the quantity of electricity transferred.

Quantity of electricity Q = It coulombs
$I = 5$ A, $t = 2 \times 60 = 120$ s
Hence $Q= 5 \times 120 = 600$ C

Problem 2. Find the force acting vertically downwards on a mass of 200 g attached to a wire.

Mass=200 g=0.2 kg and acceleration due to gravity,
g =9.81 m/s2
Force acting downwards
= weight
= mass × acceleration
= 0.2 kg× 9.81m/s2
= 1.962 N

Problem 3. A portable machine requires a force of 200 N to move it. How much work is done if the machine is moved 20 m and what average power is utilized if the movement takes 25 s?

Work done = force× distance
= 200 N× 20m

= 4 000 Nm or 4 kJ

Power = work done/ time taken

= 4000 J/ 25 s

= 160 J/s = 160W

Problem 4. A source e.m.f. of 5V supplies a current of 3A for 10 minutes. How much energy is provided in this time? Energy = power ×time, and power =voltage ×current.

Hence

= VIt = 5 × 3 × (10× 60) = 9000Ws or J = 9 kJ

Problem5. Derived SI units _use combinations of basic units and there are many of them. Two examples are:

Velocity – metres per second (m/s)

Acceleration – metres per second squared (m/s2)

Problem 6. A mass of 1000 kg is raised through a height of 10 m in 20 s. What is (a) the work done and (b) the power developed?

(a) Work done = force× distance and force
    = mass × acceleration Hence,
    Work done = (1000 kg× 9.81m/s2) × (10m) = 98 100 Nm = 98.1 kNm or 98.1 kJ
(b) Power = work done/time taken
    = 98 100 J/20 s
    = 4905 J/s
    = 4905W or 4.905 kW

3.2.2 Learning Outcome 2: D.C And A.C Circuits In Electrical Installation

3.2.3.1 Introduction to the learning outcome

To apply DC and AC circuits in an Electrical Installation one is required to understand the Meaning of terms Conductors and insulators, Ohm's law Resistance variation, Resistors and color coding.

AC and DC circuits

- R-L, R-C, R-L-C circuits
- Series
- Parallel
- Parallel and series
- Parallel resonance and Q-factor
- Power factor improvement
- AC and DC network theorems e.g Kirchhoff's laws

3.2.3.2 Performance Standard

- Theory of conductors and insulators is determined as per established procedures
- Ohm's law is performed as per established procedures
- Calculations involving resistor connection is performed as per established procedures

- Colour coding for fixed resistors is performed as per established standards
- Calculations involving parallel and series circuits are performed as per established standards
- Calculations involving R-L-C circuits are performed as per established standards
- Calculations involving DC and AC circuits. Network theorems are performed. E.g., Kirchhoff's laws,
- Conversion of AC to DC and DC to AC are performed as per established standards
- Parallel resonance and Q-factor are determined as per established standards

o Power factor improvement is performed as per established standards

3.2.3.3 Information Sheet

Meaning of term;

A conductor is a material having a low resistance which allows electric current to flow in it. All metals are conductors and some examples include copper, aluminium, brass, platinum, silver, gold and carbon.

An insulator is a material having a high resistance which does not allow electric current to flow in it. Some examples of insulators include plastic, rubber, glass, porcelain, air, paper, cork, mica, ceramics and certain oils.

Ohm's law states that the current I flowing in a circuit is directly proportional to the applied voltage V and inversely proportional to the resistance R, provided the temperature remains constant. Thus, I = VR or V = IR or R = V/I

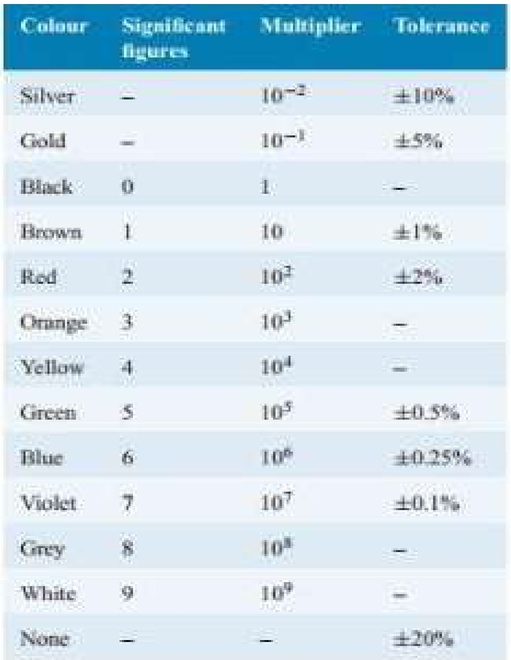
Example

The current flowing through a resistor is 0.8 A when a p.d. of 20V is applied. Determine the value of the resistance. From Ohm's law, resistance R= V/I

= 20/0.8

= 200/8

=25Ω



Colour	Significant figures	Multiplier	Tolerance
Silver	–	10^{-2}	±10%
Gold	–	10^{-1}	±5%
Black	0	1	–
Brown	1	10	±1%
Red	2	10^2	±2%
Orange	3	10^3	–
Yellow	4	10^4	–
Green	5	10^5	±0.5%
Blue	6	10^6	±0.25%
Violet	7	10^7	±0.1%
Grey	8	10^8	–
White	9	10^9	–
None	–	–	±20%

Resistor colour coding and ohmic values

(a) Colour code for fixed resistors

The colour code for fixed resistors is given in Table(i) For a four-band fixed resistor (i.e., resistance values with two significant figures): yellow-violet orange-red indicates 47 k with a tolerance of ±2%

(Note that the first band is the one nearest the end of the resistor.) (ii) For a five-band fixed resistor (i.e., resistance values with three significant figures): red-yellow white-orange-brown indicates 249 k with a tolerance of ±1% (Note that the fifth band is 1.5 to 2 times wider than the other bands.)

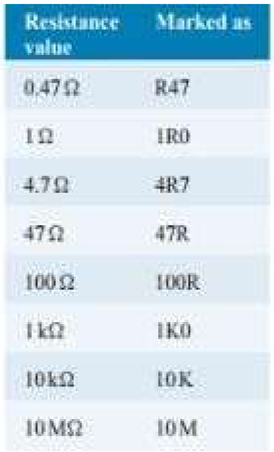
(b) Letter and digit code for resistors

Another way of indicating the value of resistors is the letter and digit code shown in Table 5.2. Tolerance is indicated as follows =±1%, G=±2%,J =±5%, K =±10% and M =±20%.Thus, for example,

R33M = 0.33 ± 20%

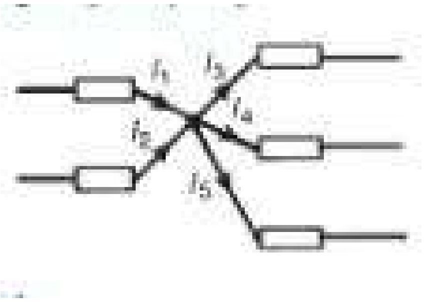
4R7K = 4.7 ± 10%

390RJ = 390 ± 5%



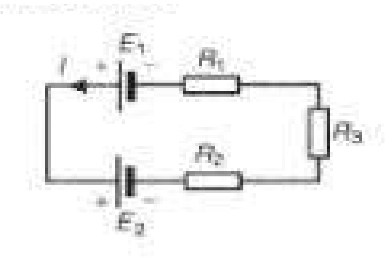
Resistance value	Marked as
0.47 Ω	R47
1 Ω	1R0
4.7 Ω	4R7
47 Ω	47R
100 Ω	100R
1 kΩ	1K0
10 kΩ	10K
10 MΩ	10M

Kirchhoff's laws



Kirchhoff's laws state:

(a) Current Law. At any junction in an electric circuit the total current flowing towards that junction is equal to the total current flowing away from the junction, i.e. I =0 Thus, referring to Fig. Below I1+I2 =I3 +I4 +I5 or I1+I2 −I3 −I4 −I5 =0



(b) Voltage Law. In any closed loop in a network, the algebraic sum of the voltage drops (i.e. products of current and resistance) taken around the loop is equal to the resultant e.m.f. acting in that loop Thus, referring to Fig. Below

$E1 - E2 = IR1 + IR2 + IR3$

(Note that if current flows away from the positive terminal of a source, that source is considered by convention to be positive. Thus, moving anticlockwise around the loop of Fig. 15.2, E1 is positive and E2 is negative.)

Series AC Circuit

R–L series a.c. circuit

In an a.c. circuit containing inductance L and resistance R, the applied voltage V is the phasor sum of VR and VL, and thus the current I lags the applied voltage V by an angle lying between 0◦ and 90◦ (depending on the values of VR and VL), shown as angle φ. In any a.c. series circuit the current is common to each component and is thus taken as the reference phasor.

Figure 15.6

From the phasor diagram of Fig. 15.6, the **'voltage triangle'** is derived.

For the R–L circuit:

$$V = \sqrt{V_R^2 + V_L^2} \quad \text{(by Pythagoras' theorem)}$$

and

$$\tan\phi = \frac{V_L}{V_R} \quad \text{(by trigonometric ratios)}$$

In an a.c. circuit, the ratio applied voltage V to current I is called the **impedance**, Z, i.e.

$$Z = \frac{V}{I}\ \Omega$$

If each side of the voltage triangle in Fig. 15.6 is divided by current I then the **'impedance triangle'** is derived.

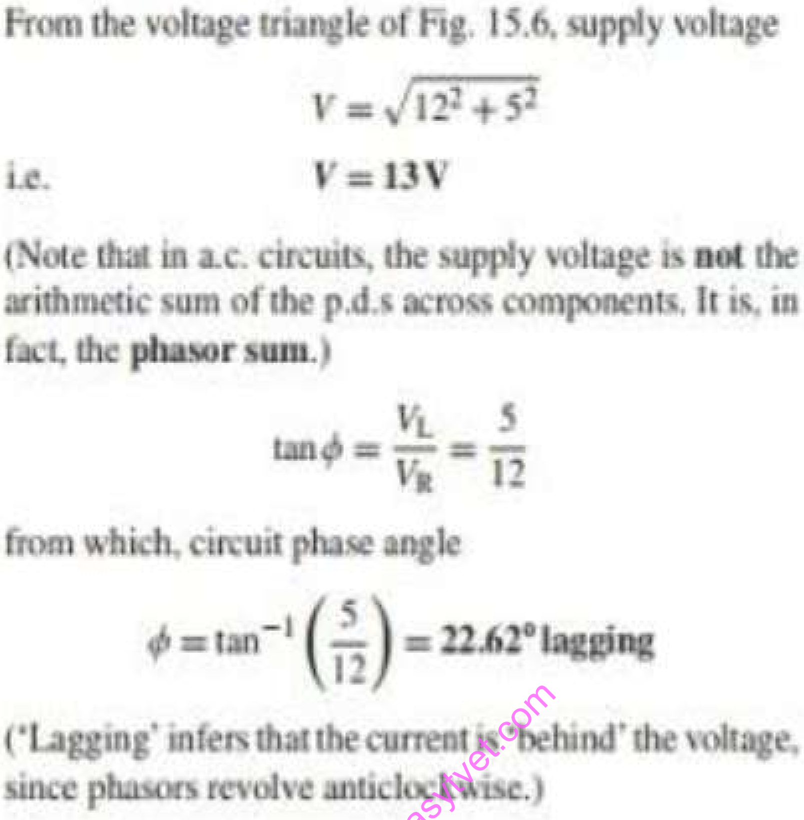
For the R–L circuit: $Z = \sqrt{R^2 + X_L^2}$

$$\tan\phi = \frac{X_L}{R}$$

$$\sin\phi = \frac{X_L}{Z}$$

and

$$\cos\phi = \frac{R}{Z}$$



From the voltage triangle of Fig. 15.6, supply voltage

$$V = \sqrt{12^2 + 5^2}$$

i.e. $$V = 13\,\mathbf{V}$$

(Note that in a.c. circuits, the supply voltage is **not** the arithmetic sum of the p.d.s across components. It is, in fact, the **phasor sum**.)

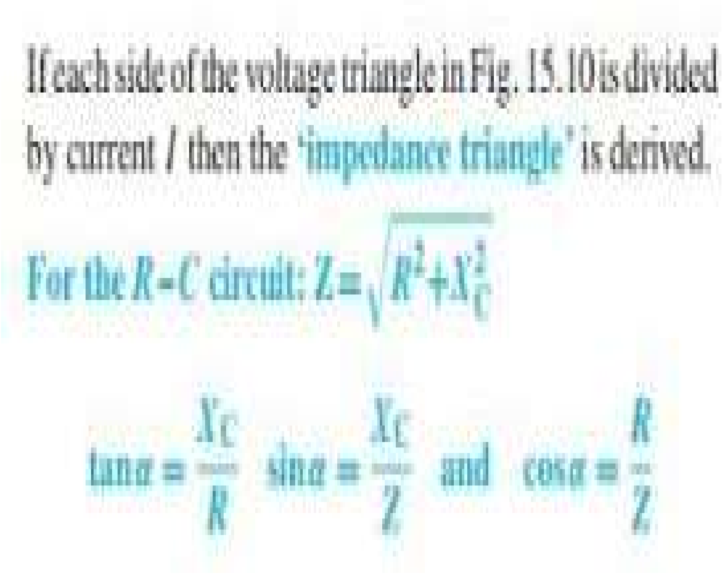
$$\tan\phi = \frac{V_L}{V_R} = \frac{5}{12}$$

from which, circuit phase angle

$$\phi = \tan^{-1}\left(\frac{5}{12}\right) = \mathbf{22.62^\circ\ lagging}$$

('Lagging' infers that the current is 'behind' the voltage, since phasors revolve anticlockwise.)

Example1. In a series R–L circuit the p.d. across the resistance R is 12V and the p.d. across the inductance L is 5V. Find the supply voltage and the phase angle between current and voltage



If each side of the voltage triangle in Fig. 15.10 is divided by current I then the 'impedance triangle' is derived.

For the R–C circuit: $Z=\sqrt{R^2+X_C^2}$

$$\tan\alpha=\frac{X_C}{R}\quad \sin\alpha=\frac{X_C}{Z}\quad \text{and}\quad \cos\alpha=\frac{R}{Z}$$

R–C series a.c. circuit

In an a.c. series circuit containing capacitance C and resistance R, the applied voltage V is the phasor sum of VR and VC and thus the current I leads the applied voltage V by an angle lying between 0◦ and 90◦ (depending on the values of VR and VC), shown as angle α

From the phasor diagram, the ‘voltage triangle’ is derived.

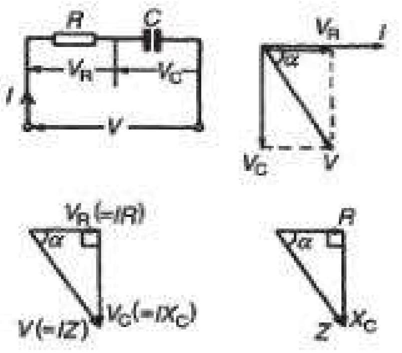
For the $R-C$ circuit:

$$V = \sqrt{V_R^2 + V_C^2} \quad \text{(by Pythagoras' theorem)}$$

and

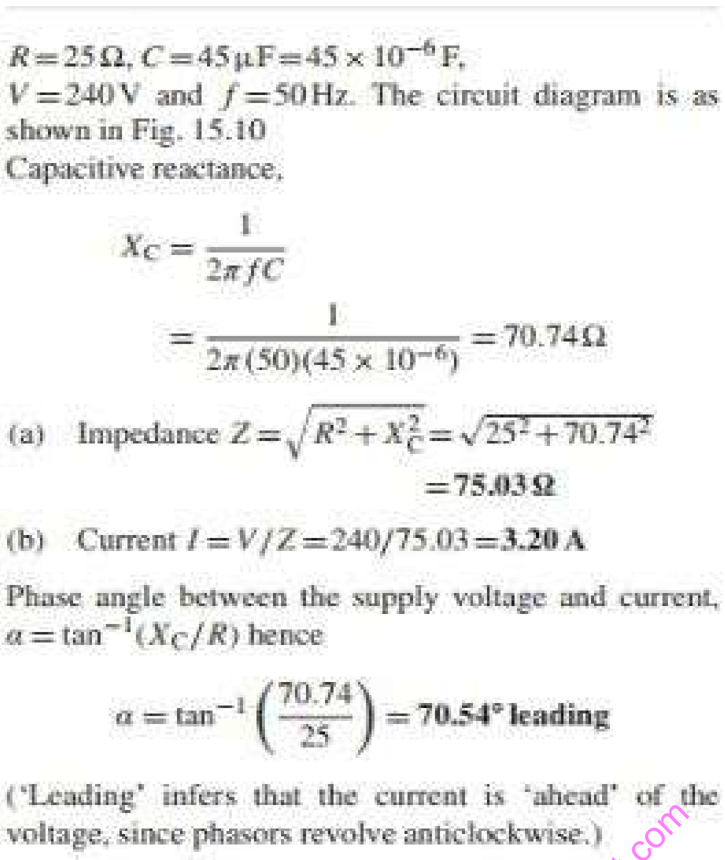
$$\tan\alpha = \frac{V_C}{V_R} \quad \text{(by trigonometric ratios)}$$

As stated in Section 15.4, in an a.c. circuit, the ratio of applied voltage V to current I is called the **impedance** Z, i.e. $Z = V/I\ \Omega$



Example 1

A resistor of 25Ω is connected in series with a capacitor of 45µF. Calculate (a) the Impedance and (b) the current taken from a 240 V, 50 Hz supply. Find also the phase angle between the supply voltage and the current.



$R = 25\,\Omega$, $C = 45\,\mu\text{F} = 45 \times 10^{-6}\,\text{F}$, $V = 240\,\text{V}$ and $f = 50\,\text{Hz}$. The circuit diagram is as shown in Fig. 15.10

Capacitive reactance,

$$X_C = \frac{1}{2\pi f C}$$

$$= \frac{1}{2\pi(50)(45 \times 10^{-6})} = 70.74\,\Omega$$

(a) Impedance $Z = \sqrt{R^2 + X_C^2} = \sqrt{25^2 + 70.74^2}$

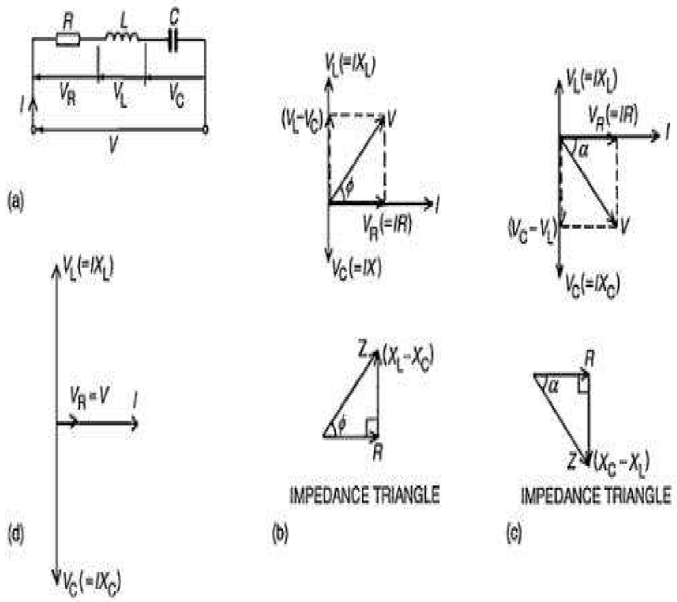
$$= \mathbf{75.03\,\Omega}$$

(b) Current $I = V/Z = 240/75.03 = \mathbf{3.20\,A}$

Phase angle between the supply voltage and current, $\alpha = \tan^{-1}(X_C/R)$ hence

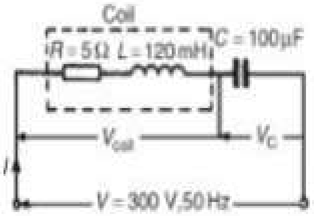
$$\alpha = \tan^{-1}\left(\frac{70.74}{25}\right) = \mathbf{70.54^\circ\ leading}$$

('Leading' infers that the current is 'ahead' of the voltage, since phasors revolve anticlockwise.)



R–L–C series a.c. circuit

In an a.c. series circuit containing resistance R, inductance L and capacitance C, the applied voltage V is the phasor sum of VR, VL and VC. VL and VC are anti-phase, i.e. displaced by 180◦, and there are three phasor diagrams possible – each depending on the relative values of VL and V



$_{\text{L}} - X_{\text{C}})^2$

When $X_C > X_L$ (Fig. 15.12(c)):

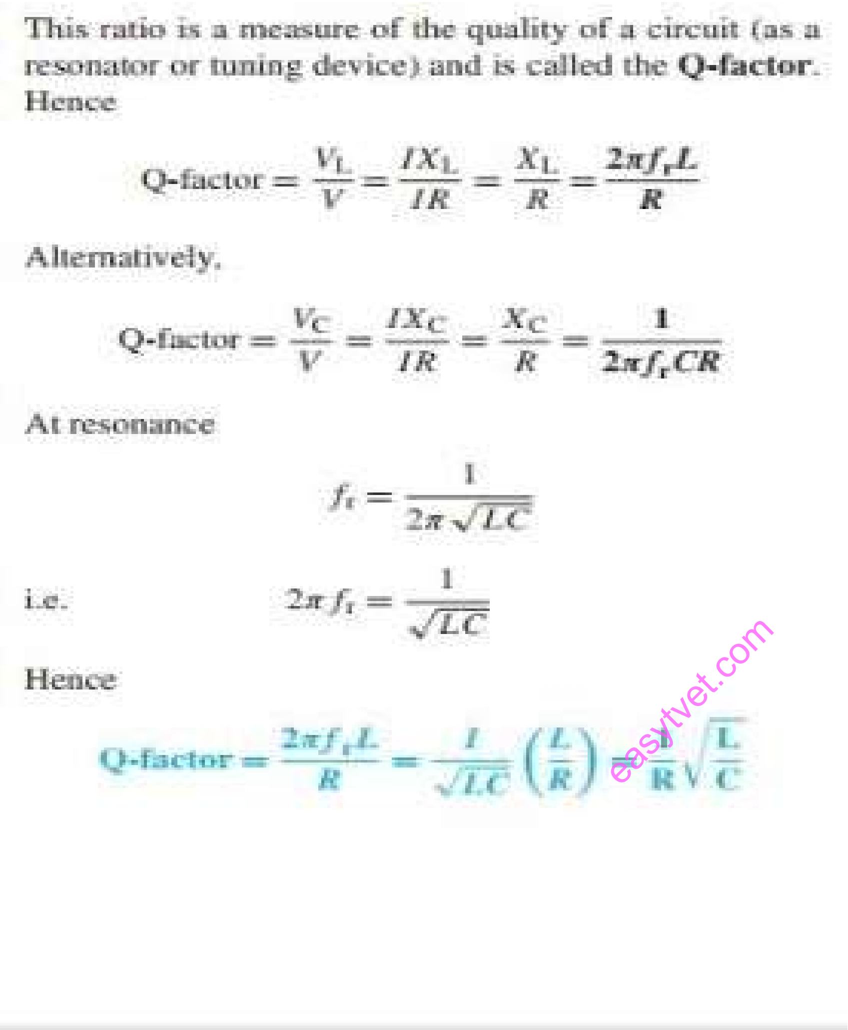
$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

and $$\tan \alpha = \frac{X_C - X_L}{R}$$

When $X_L = X_C$ (Fig. 15.12(d)), the applied voltage V and the current I are in phase. This effect is called **series**

Example 1

A coil of resistance 5 and inductance 120 mH in series with a 100μF capacitor is connected to a 300 V, 50Hz supply. Calculate (a) the current flowing, (b) the phase difference between the supply voltage and current,(c) the voltage across the coil and (d) the voltage across the capacitor.



This ratio is a measure of the quality of a circuit (as a resonator or tuning device) and is called the **Q-factor**. Hence

$$\text{Q-factor} = \frac{V_L}{V} = \frac{IX_L}{IR} = \frac{X_L}{R} = \frac{2\pi f_r L}{R}$$

Alternatively,

$$\text{Q-factor} = \frac{V_C}{V} = \frac{IX_C}{IR} = \frac{X_C}{R} = \frac{1}{2\pi f_r CR}$$

At resonance

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

i.e.

$$2\pi f_r = \frac{1}{\sqrt{LC}}$$

Hence

$$\text{Q-factor} = \frac{2\pi f_r L}{R} = \frac{1}{\sqrt{LC}}\left(\frac{L}{R}\right) = \frac{1}{R}\sqrt{\frac{L}{C}}$$

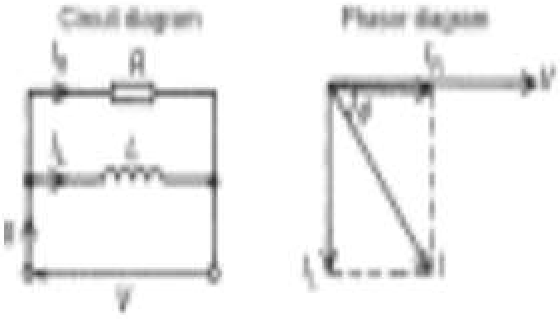
Q-factor

At resonance, if R is small compared with XL and XC, it is possible for VL and VC to have voltages many times greater than the supply voltage .Voltage magnification at resonance= voltage across L (or C)supply voltage V .This ratio is a measure of the quality of a circuit (as a resonator or tuning device) and is called the Q-factor. Hence

PARALLEL CIRCUIT

R-L ac circuit

In the two-branch parallel circuit containing resistance R and inductance L,the current flowing in the resistance, IR, is in-phase with the supply voltage V and the current flowing in the inductance, IL, lags the supply voltage by 90°. The supply current I is the phasor sum of IR and IL and thus the current I lags the applied voltage V by an angle lying between 0◦ and 90◦ (depending on the values of IR and IL), shown as angle φ in the phasor diagram.



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From the phasor diagram: $I=\sqrt{I_R^2+I_L^2}$ (by Pythagoras' theorem) where

$$I_R=\frac{V}{R} \text{ and } I_L=\frac{V}{X_L}$$

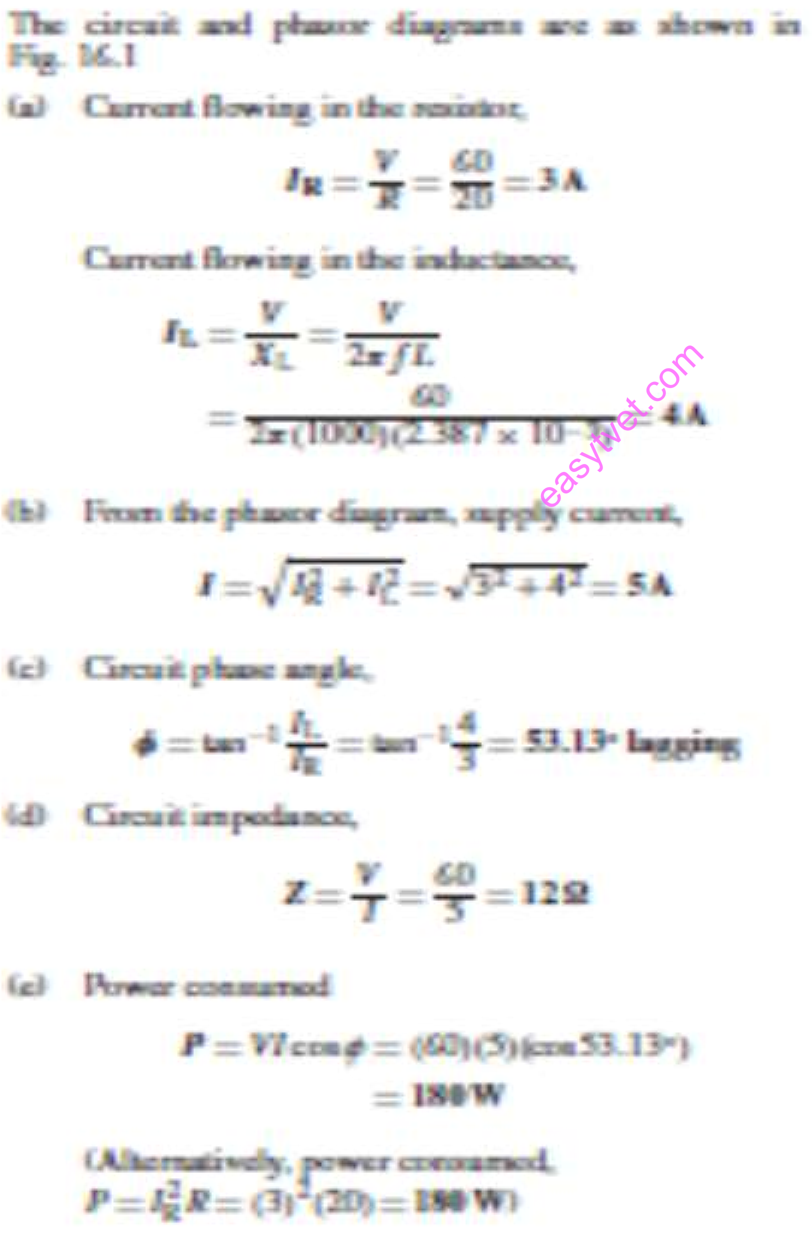
$$\tan\phi=\frac{I_L}{I_R},\ \sin\phi=\frac{I_L}{I} \text{ and } \cos\phi=\frac{I_R}{I}$$

(by trigonometric ratios)

$$\text{Circuit impedance, } Z=\frac{V}{I}$$

EXAMPLE1

A 20_ resistor is connected in parallel with an inductance of 2.387mH across a 60V, 1 kHz supply. Calculate (a) the current in each branch, (b) the supply current, (c) the circuit phase angle, (d) the circuit impedance and (e) the power consumed.



The circuit and phasor diagrams are as shown in Fig. 16.1

(a) Current flowing in the resistor,

$$I_R = \frac{V}{R} = \frac{60}{20} = 3\,\text{A}$$

Current flowing in the inductance,

$$I_L = \frac{V}{X_L} = \frac{V}{2\pi f L} = \frac{60}{2\pi(1000)(2.387 \times 10^{-3})} = 4\,\text{A}$$

(b) From the phasor diagram, supply current,

$$I = \sqrt{I_R^2 + I_L^2} = \sqrt{3^2 + 4^2} = 5\,\text{A}$$

(c) Circuit phase angle,

$$\phi = \tan^{-1}\frac{I_L}{I_R} = \tan^{-1}\frac{4}{3} = 53.13^\circ \text{ lagging}$$

(d) Circuit impedance,

$$Z = \frac{V}{I} = \frac{60}{5} = 12\,\Omega$$

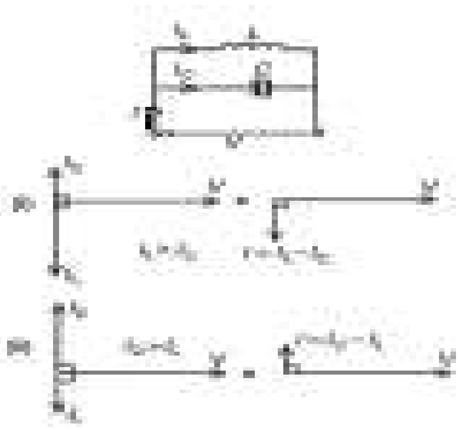
(e) Power consumed

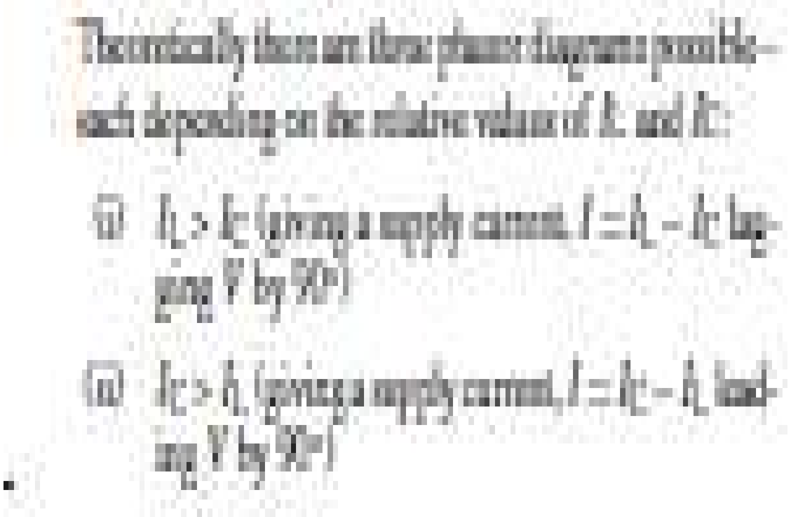
$$P = VI\cos\phi = (60)(5)(\cos 53.13^\circ) = 180\,\text{W}$$

(Alternatively, power consumed, $P = I_R^2 R = (3)^2(20) = 180\,\text{W}$)

L-C ac circuit

In the two-branch parallel circuit containing inductance L and capacitance C, IL lags V by 900 and IC leads V by 900.

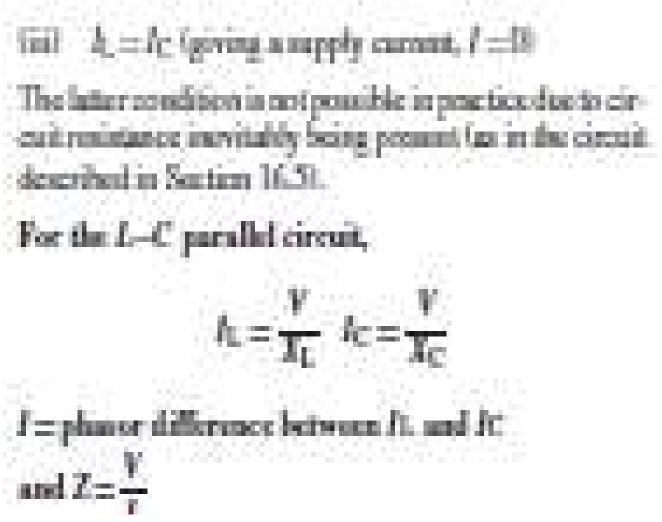




Theoretically there are three phasor diagrams possible—each depending on the relative values of I_L and I_C:

(i) $I_L > I_C$ (giving a supply current, $I = I_L - I_C$ lagging V by 90°)

(ii) $I_C > I_L$ (giving a supply current, $I = I_C - I_L$ leading V by 90°)



(iii) $I_L = I_C$ (giving a supply current, $I = 0$)

The latter condition is not possible in practice due to circuit resistance inevitably being present (as in the circuit described in Section 16.3).

For the L–C parallel circuit,

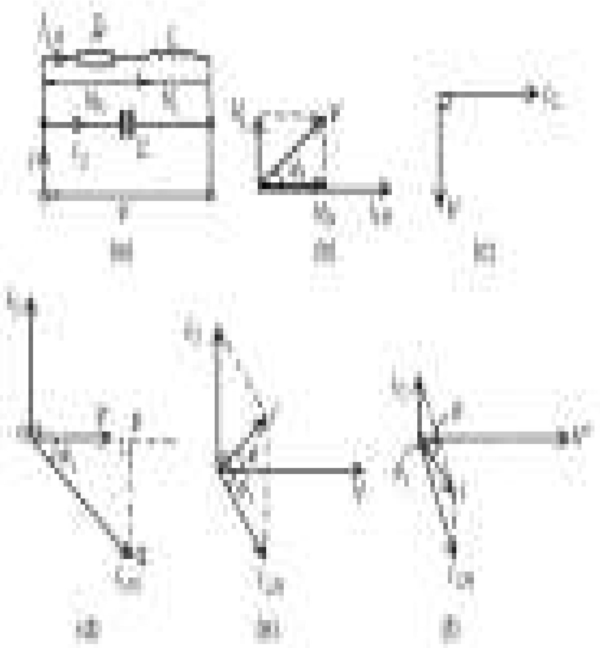
$$I_L = \frac{V}{X_L} \quad I_C = \frac{V}{X_C}$$

I = phasor difference between I_L and I_C

and $Z = \frac{V}{I}$

LR-C ac circuit

In the two-branch circuit containing capacitance C in parallel with inductance L and resistance R in series (such as a coil)shown in Fig(a),the phasor diagram for the LR branch alone is shown in Fig.(b) and the phasor diagram for the C branch is shown alone in Fig. (c). Rotating each and superimposing on one another gives the complete phasor diagram shown in Fig(d).


R
L
C
V
(a)
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(e)
(f)

The current I_{LR} of Fig. 16.5(d) may be resolved into horizontal and vertical components. The horizontal component, shown as *op* is $I_{LR} \cos \phi_1$ and the vertical component, shown as *pq* is $I_{LR} \sin \phi_1$. There are three possible conditions for this circuit:

(i) $I_C > I_{LR} \sin \phi_1$ (giving a supply current I leading V by angle ϕ – as shown in Fig. 16.5(e))

(ii) $I_{LR} \sin\phi > I_C$ (giving I lagging V by angle ϕ—as shown in Fig. 16.5(f))

(iii) $I_C = I_{LR} \sin\phi_1$ (this is called **parallel resonance**, see Section 16.6)

There are two methods of finding the phasor sum of currents I_{LR} and I_C in Fig. 16.5(e) and (f). These are: (i) by a scaled phasor diagram, or (ii) by resolving each current into their '**in-phase**' (i.e. horizontal) and '**quadrature**' (i.e. vertical) **components**, as demonstrated in Problems 6 and 7. With reference to the phasor diagrams of Fig. 16.5:

Impedance of LR branch, $Z_{LR} = \sqrt{R^2 + X_L^2}$

Current, $I_{LR} = \dfrac{V}{Z_{LR}}$ and $I_C = \dfrac{V}{X_C}$

Supply current

I = phasor sum of I_{LR} and I_C (by drawing)

$$= \sqrt{(I_{LR}\cos\phi_1)^2 + (I_{LR}\sin\phi_1 \sim I_C)^2}$$

(by calculation)

where $\sim$ means 'the difference between'.

$$\text{Circuit impedance } Z = \frac{V}{I}$$

$$\tan\phi_1 = \frac{V_L}{V_R} = \frac{X_L}{R}$$

$$\sin\phi_1 = \frac{X_L}{Z_{LR}} \quad \text{and} \quad \cos\phi_1 = \frac{R}{Z_{LR}}$$

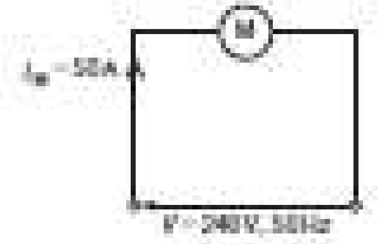
$$\tan\phi = \frac{I_{LR}\sin\phi_1 \sim I_C}{I_{LR}\cos\phi_1} \quad \text{and} \quad \cos\phi = \frac{I_{LR}\cos\phi_1}{I}$$

POWER IMPROVEMENT

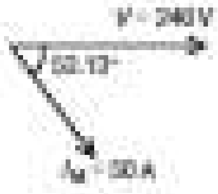
In any a.c. circuit, power factor =cosφ,where φ is the phase angle between supply current and supply voltage. Industrial loads such as a.c. motors are essentially inductive (i.e. R–L) and may have a low power factor. For example, let a motor take a current of 50A at a power factor of 0.6 lagging from a 240V, 50Hz supply, as shown in the circuit diagram of Fig(a).

If power factor = 0.6 lagging, then: cosφ = 0.6 lagging

Hence, phase angle, φ = cos−1 0.6 = 53.13◦ lagging, Lagging means that I lags V , and the phasor diagram is as shown in Fig(b).

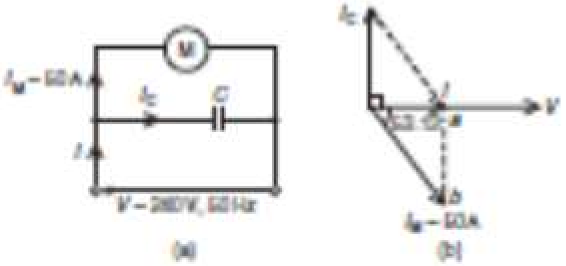


(a)



(b)

How can this power factor of 0.6 be 'improved' or 'corrected' to, say, unity? Unity power factor means: cosφ = 1 from which, φ = 0 So how can the circuit of Fig(a) be modified so that the circuit phase angle is changed from53.13◦ to 0◦? The answer is to connect a capacitor in parallel with the motor as shown in Fig(a).



When a capacitor is connected in parallel with the inductive load, it takes a current shown as IC. In the phasor diagram of Fig(b), current IC is shown leading the voltage V by 90◦.The supply current in Fig(a) is shown as I and is now the phasor sum of IM and IC In the phasor diagram of Fig(b), current I is shown as the phasor sum of IM and IC and is in phase with V , i.e. the circuit phase angle is 0◦, which means that the power factor is cos 0◦= 1

Thus, by connecting a capacitor in parallel with the motor, the power factor has been improved from 0.6 lagging to unity.

From right-angle triangles,cos 53.13◦ = adjacent/hypotenuse

= I/50

from which, supply current, I = 50 cos 53.13◦

= 30A

Before the capacitor was connected, the supply current was 50A. Now it is 30 A.

Herein lies the advantage of power factor improvement– the supply current has been reduced. When power factor is improved, the supply current is reduced, the supply system has lower losses (i.e. Lower I 2R losses) and therefore cheaper running costs.

3.2.3.4 Learning Activities

Determined theory of conductors and insulators as per established procedures

- Performed Ohms law as per established procedures
- Performed calculations involving resistor connection as per established procedures
- Performed color coding for fixed resistors as per established standards
- Performed calculations involving parallel and series circuits as per established standards
- Performed calculations involving R-L-C circuits as per established standards
- Performed calculations involving DC and AC circuits. Network theorems . E.g. Kirchoff’s laws,
- Performed conversion of AC to DC and DC to AC as per established standards
- Determined parallel resonance and Q-factor as per established standards
- Performed power factor improvement as per established standards

3.2.3.5 Self-Assessment

1. Define the following terms;

I. A conductor

II. An insulator.

2. State ;

I. Kirchhoff’s laws

II. Ohm’s law.

3. What is Q-factor

4. A resistor of 25Ω is connected in series with a capacitor of 45μF. Calculate (a) the Impedance and (b) the current taken from a 240 V, 50 Hz supply. Find also the phase angle between the supply voltage and the current.

5. In a series R–L circuit the p.d. across the resistance R is 12V and the p.d. across the inductance L is 5V. Find the supply voltage and the phase angle between current and voltage

3.2.2.6 Tools, Equipment, Supplies and Material

- Scientific calculators
- Ohmeter
- Resistors
- Conductor

3.2.2.7 References

- o John Bird(2017) Electrical and Electronics Principles Technology fifth Edition
- o John Bird(2017) Electrical and Electronics Principles Technology sixth Edition
- o Watkins, A.J, Kitcher C (2009) Electrical Installation calculations Basic Eighth Elsevier Ltd
- o Stokes,J Handbook of Electrical Installation Practice Fourth Edition Blackwell Science Ltd

3.2.2.8 Response To Self-Assessment.

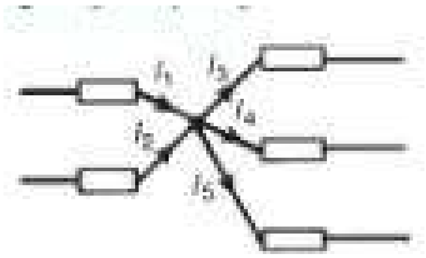
II. A conductor is a material having a low resistance which allows electric current to flow in it. All metals are conductors and some examples include copper, aluminum, brass, platinum, silver, gold and carbon.

III. An insulator is a material having a high resistance which does not allow electric current to flow in it. Some examples of insulators include plastic, rubber, glass, porcelain, air, paper, cork, mica, ceramics and certain oils.

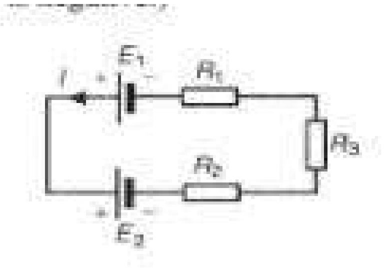
2. Kirchhoff's laws state:

(a) Current Law. At any junction in an electric circuit the total current flowing towards that junction is equal to the total current flowing away from the junction, i.e. $I = 0$ Thus, referring to Fig. Below $I1+I2 = I3 + I4 + I5$ or $I1+I2 - I3 - I4 - I5 = 0$

(b) Voltage Law. In any closed loop in a network, the algebraic sum of the voltage drops (i.e. products of current and resistance) taken around the loop is equal to the resultant e.m.f. acting in that loop Thus, referring to Fig. Below



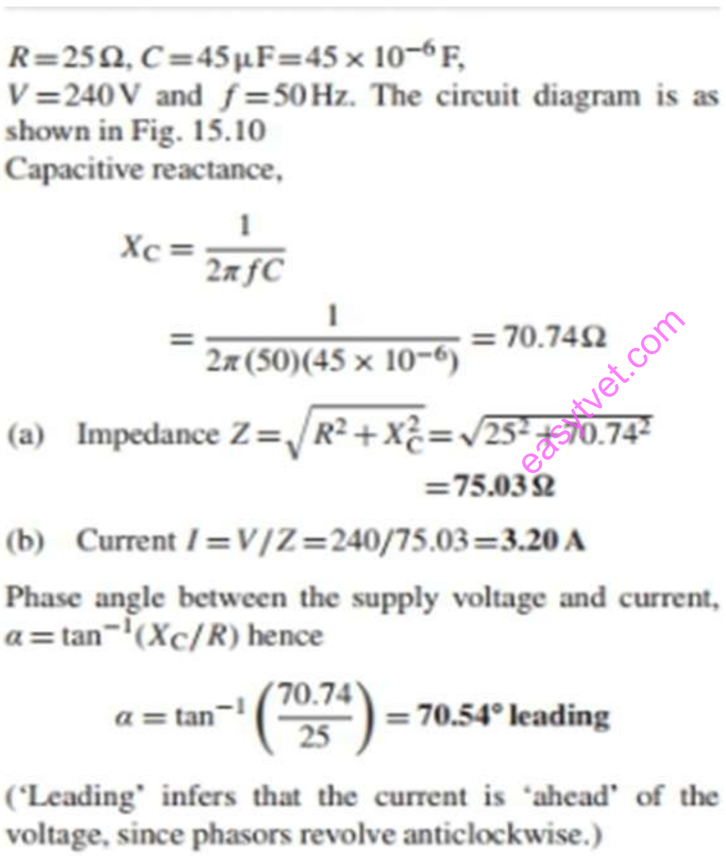
$E1 - E2 = IR1 + IR2 + IR3$



Ohm’s law states that the current I flowing in a circuit is directly proportional to the applied voltage V and inversely proportional to the resistance R, provided the temperature remains constant. Thus, $I = VR$ or $V = IR$ or $R = V/I$

3.Q-factor. At resonance, if R is small compared with XL and XC, it is possible for VL and VC to have voltages many times greater than the supply voltage .Voltage magnification at resonance= voltage across L (or C)supply voltage V .This ratio is a measure of the quality of a circuit (as a resonator or tuning device) and is called the Q-factor.

4. A resistor of 25Ω is connected in series with a capacitor of 45μF. Calculate (a) the Impedance and (b) the current taken from a 240 V, 50 Hz supply. Find also the phase angle between the supply voltage and the current.



$R=25\,\Omega$, $C=45\,\mu\text{F}=45\times10^{-6}\,\text{F}$, $V=240\,\text{V}$ and $f=50\,\text{Hz}$. The circuit diagram is as shown in Fig. 15.10

Capacitive reactance,

$$X_C=\frac{1}{2\pi fC}$$

$$=\frac{1}{2\pi(50)(45\times10^{-6})}=70.74\,\Omega$$

(a) Impedance $Z=\sqrt{R^2+X_C^2}=\sqrt{25^2+70.74^2}$ $=\mathbf{75.03\,\Omega}$

(b) Current $I=V/Z=240/75.03=\mathbf{3.20\,A}$

Phase angle between the supply voltage and current, $\alpha=\tan^{-1}(X_C/R)$ hence

$$\alpha=\tan^{-1}\left(\frac{70.74}{25}\right)=\mathbf{70.54°\ leading}$$

('Leading' infers that the current is 'ahead' of the voltage, since phasors revolve anticlockwise.)

5. In a series R–L circuit the p.d. across the resistance R is 12V and the p.d. across the inductance L is 5V. Find the supply voltage and the phase angle between current and voltage

From the voltage triangle of Fig. 15.6, supply voltage

$$V = \sqrt{12^2 + 5^2}$$

i.e. $$\mathbf{V = 13\,V}$$

(Note that in a.c. circuits, the supply voltage is **not** the arithmetic sum of the p.d.s across components. It is, in fact, the **phasor sum**.)

$$\tan\phi = \frac{V_L}{V_R} = \frac{5}{12}$$

from which, circuit phase angle

$$\phi = \tan^{-1}\left(\frac{5}{12}\right) = \mathbf{22.62^\circ\ lagging}$$

('Lagging' infers that the current is 'behind' the voltage, since phasors revolve anticlockwise.)

3.2.3 Learning Outcome 3: Electrical Machines

3.2.3.1 Introduction to the learning outcome

To operate Electrical machines correctly one is required to have knowledge on Single phase Electrical machines, DC single phase motors and generators, AC Single phase motors and generators, Single phase transformers, Application of AC and DC machines, Motor starter, DC Motor speed control

3.2.3.2 Performance Standard

- Types of single-phase electrical machines are identified as per established standards
- Calculations involving single phase AC and DC Motors are performed per established standards
- Types of single-phase transformers are identified as per established standards
- Calculations involving single AC and DC transformers are performed as per established standards
- Types of single-phase generators are identified as per established standards
- Motor starting methods are identified as per established procedure
- DC motor speed control is established as per standard operating procedures

3.2.3.3 Information Sheet

DC Generators

D.c generators are classified according to the method of their field excitation. These groupings are:

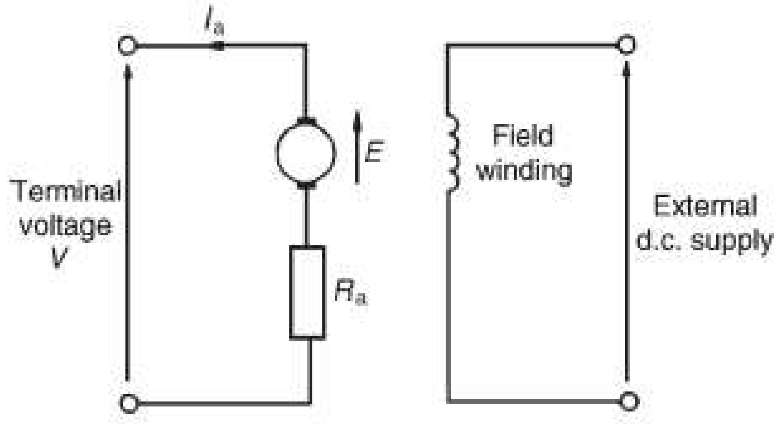
(i) Separately excited generators, where the field winding is connected to a source of supply other than the armature of its own machine.

(ii) Self-excited generators, where the field winding receives its supply from the armature of its own machine, and which are sub-divided into (a) shunt, (b) series and (c) compound wound generators.

Types of DC Generators

(a) Separately excited generator

A typical separately-excited generator circuit is shown below. When a load is connected across the armature terminals, a load current Ia will flow. The terminal voltage will fall from its open-circuit e.m.f. E due to a volt drop caused by current flowing through the armature resistance, shown as Ra i.e. terminal voltage, $V = E - I_aR_a$ or generated e.m.f., $E = V + I_aR_a$



EXAMPLE

Determine the terminal voltage of a generator which develops an e.m.f. of 200V and has an armature current of 30A on load. Assume the armature resistance is 0.30, terminal voltage,

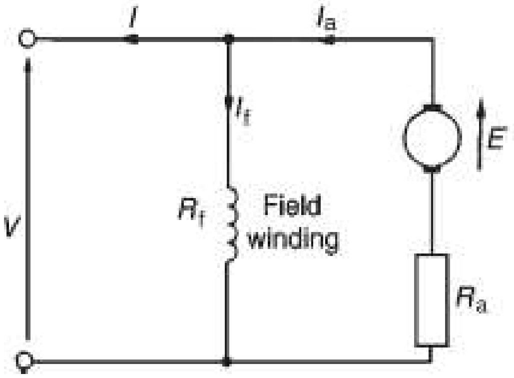
V = $E - Ia\ Ra$

= 200−(30)(0.30)

= 200−9 = 191volts

(b) Shunt-wound generator

In a shunt-wound generator the field winding is connected in parallel with the armature, The field winding has a relatively high resistance and therefore the current carried is only a fraction of the armature current.



Terminal voltage, $V=E-IaRa$ or generated e.m.f., $E=V+IaRa$

$Ia=If+I$ from Kirchhoff’s current law, where

Ia = armature current, If = field current ($=V/Rf$) and

I = load current

EXAMPLE

A shunt generator supplies a 20Kw load at 200V through cables of resistance, R = 100m_. If the field winding resistance, Rf = 50_ and the armature resistance, Ra = 40m_, determine (a) the terminal voltage and(b) the e.m.f. generated in the armature.

(a)The circuit is shown below

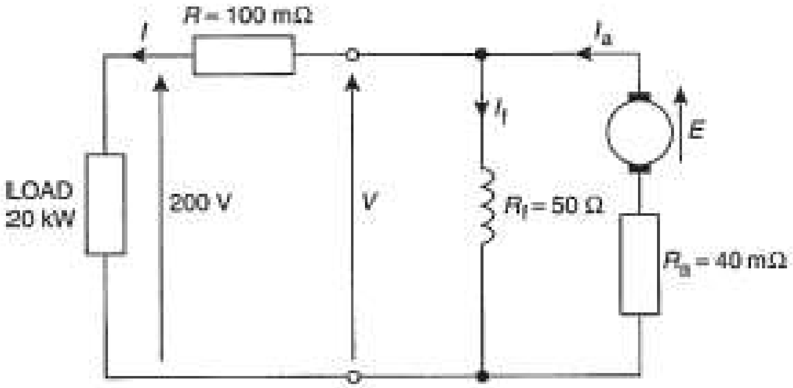
Load current, I = 20000watts/200volts

= 100A

Volt drop in the cables to the load

$=IR = (100)\ (100\times10-3) = 10V$

Hence terminal voltage=200+10=210volts



(b) Armature current $I_a = I_f + I$

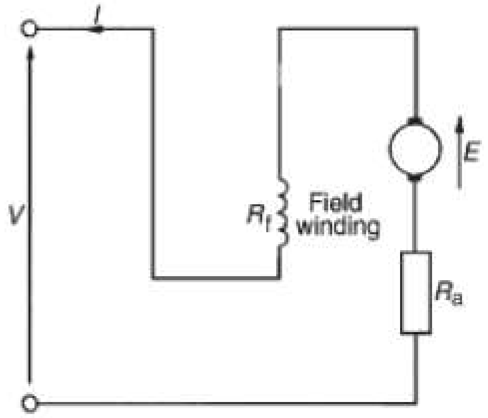
$$\text{Field current, } I_f = \frac{V}{R_f} = \frac{210}{50} = 4.2\,\text{A}$$

$$\text{Hence } I_a = I_f + I = 4.2 + 100 = 104.2\,\text{A}$$

$$\textbf{Generated e.m.f. } \boldsymbol{E} = V + I_a R_a$$
$$= 210 + (104.2)(40 \times 10^{-3})$$
$$= 210 + 4.168$$
$$= \mathbf{214.17\ volts}$$

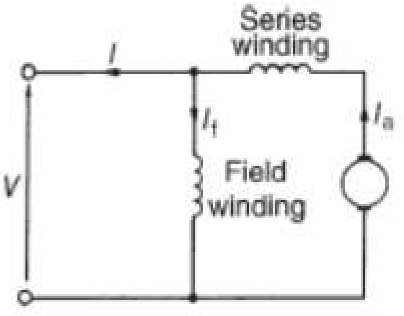
(c) Series-wound generator

In the series-wound generator the field winding is connected in series with the armature, as shown below

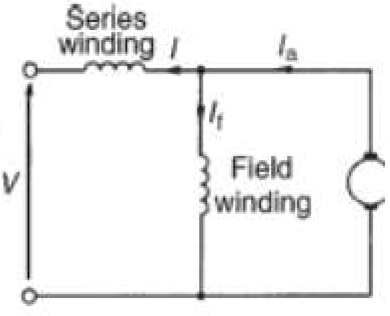


[d]. Compound-wound generator

In the compound-wound generator two methods of connection are used, both having a mixture of shunt and series windings, designed to combine the advantages of each. (a) shows what is termed a long shunt compound generator, (b) shows short-shunt compound generator. The latter is the most generally used form of d.c. generator.



(a)



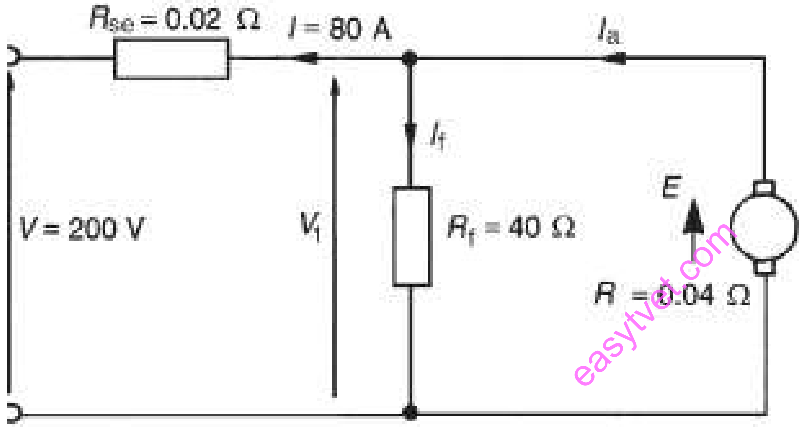
(b)

EXAMPLE

A short-shunt compound generator supplies 80A at 200V. If the field resistance, Rf = 40_, the series resistance, RSe = 0.02_ and the armature resistance, Ra = 0.04_, determine the e.m.f. generated.

Volt drop in series winding = IRSe = (80/)(0.02)

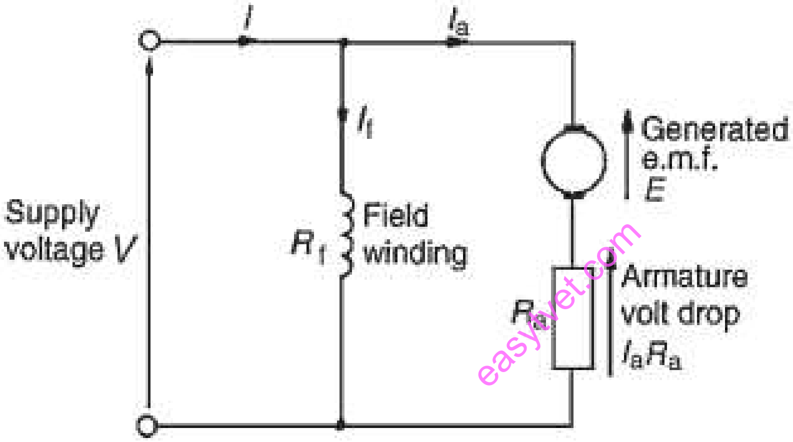
= 1.6V



TYPES OF DC MOTORS

(a) Shunt-wound motor

In the shunt-wound motor the field winding is in parallel with the armature across the supply, as shown in the figure below



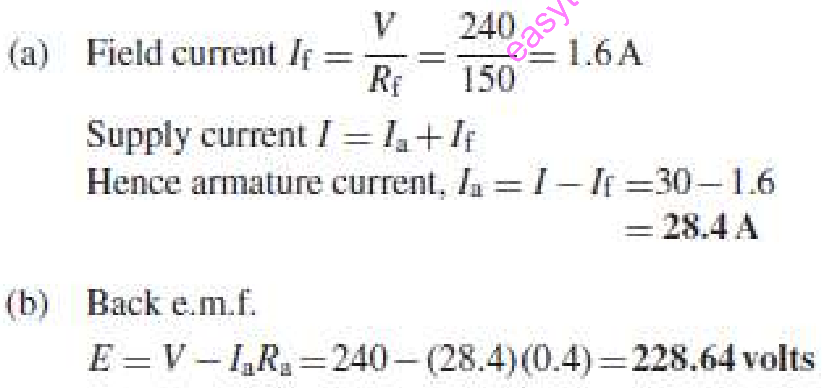
Supply voltage, V=E+IaRa or generated e.m.f., E= V−IaRa

Supply current, I=Ia+If from Kirchhoff's current law

EXAMPLE

A 240V shunt motor takes a total current of 30A. If the field winding resistance Rf = 150_ and the armature resistance Ra = 0.4_, determine (a) the current in the armature and (b) the back e.m.f.

= 28.4A



(a) Field current $I_f = \frac{V}{R_f} = \frac{240}{150} = 1.6\,\text{A}$

Supply current $I = I_a + I_f$

Hence armature current, $I_a = I - I_f = 30 - 1.6$

$= \mathbf{28.4\,A}$

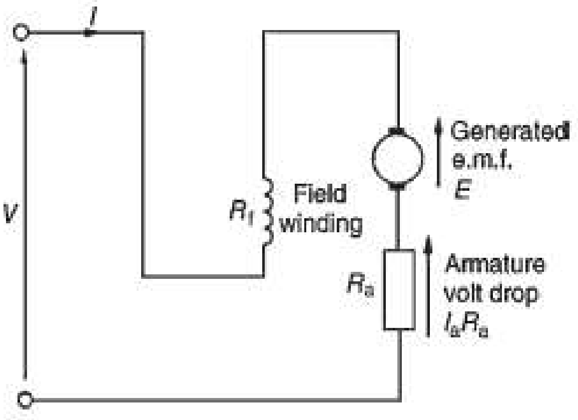
(b) Back e.m.f.

$E = V - I_aR_a = 240 - (28.4)(0.4) = \mathbf{228.64\ volts}$

(b) Series-wound motor

In the series-wound motor the field winding is in series with the armature across the supply, as shown below.

Supply voltage $V=E+I(Ra+Rf)$ *or generated e.m.f.* $E=V-I(Ra+Rf)$



(c) Compound-wound motor

There are two types of compound-wound motor:

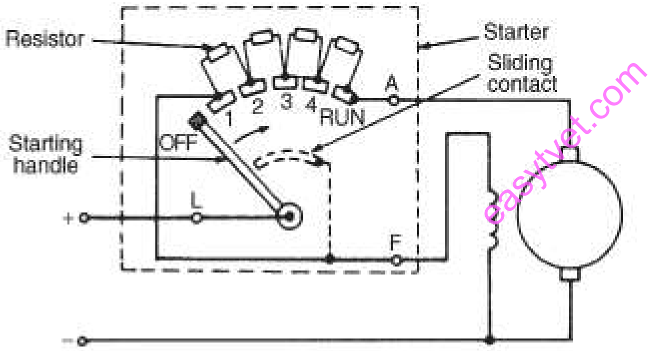
(i) Cumulative compound, in which the series winding is so connected that the field due to it assists that due to the shunt winding.

(ii) Differential compound, in which the series winding is so connected that the field due to it opposes that due to the shunt winding.

DC MOTOR STOTOR

If a d.c. motor whose armature is stationary is switched directly to its supply voltage, it is likely that the fuses protecting the motor will burn out. This is because the armature resistance is small, frequently being less than one ohm. Thus, additional resistance must be added to the armature circuit at the instant of closing the switch to start the motor.As the speed of the motor increases, the armature conductors are cutting flux and a generated voltage, acting in opposition to the applied voltage, is produced, which limits the flow of armature current. Thus the value of the additional armature resistance can then be reduced.

When at normal running speed, the generated e.m.f. is such that no additional resistance is required in the armature circuit. To achieve this varying resistance in the armature circuit on starting, a d.c. motor starter is used, as shown in Fig below



The starting handle is moved slowly in a clockwise direction to start the motor. For a shunt-wound motor, the field winding is connected to stud 1 or to L via a sliding contact on the starting handle, to give maximum field current, hence maximum flux, hence maximum torque on starting, since T $\propto I_a$ .A similar arrangement without the field connection is used for series motors

SPEED CONTROL OF DC MOTORS

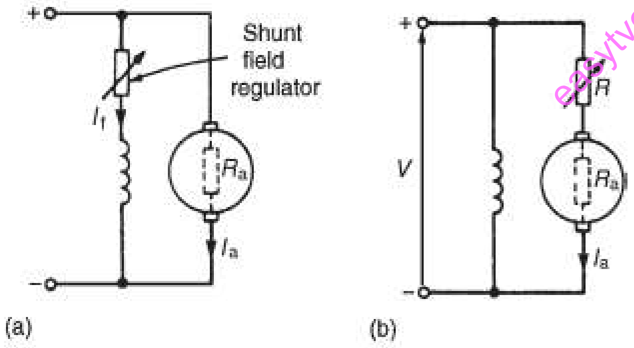
Shunt-wound motors

The speed of a shunt-wound d .c. motor, n, is proportional to

$V - I_a R_a$

Φ

The speed is varied either by varying the value of flux, or by varying the value of Ra. The former is achieved by using a variable resistor in series with the field winding, as shown in Fig below and such a resistor is called the shunt field regulator



As the value of resistance of the shunt field regulator is increased, the value of the field current, If, is decreased. This results in a decrease in the value of flux, , and hence an increase in the speed, since $n \propto 1/$. Thus only speeds above that given without a shunt field regulator can be obtained by this method. Speeds below those given by

$$V - IaRa/\Phi$$

are obtained by increasing the resistance in the armature circuit, where

$n \propto$

$$V - Ia(Ra+R)/\Phi$$

Since resistor R is in series with the armature, it carries the full armature current and results in large power loss in large motors where a considerable speed reduction is required for long periods.

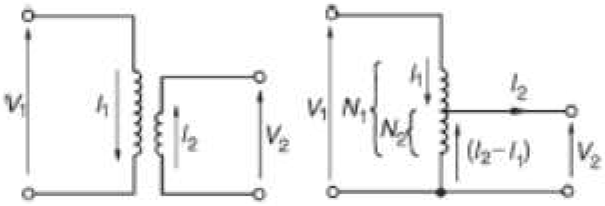
These methods of speed control are demonstrated in the following worked problem.

TRANSFOMER

An auto transformer is a transformer which has part of its winding common to the primary and secondary

Circuits. Fig(a) shows the circuit for a double wound transformer and Fig(b) that for an auto transformer. The latter shows that the secondary is actually part of the primary, the current in the secondary being $(I2-I1)$. Since the current is less in this section,the cross-sectional area of the winding can be reduced,

which reduces the amount of material necessary.



(a) (b)

3.2.3.4 Learning Activities

- Identified types of single-phase electrical machines as per established standards
- performed Calculations involving single phase AC and DC Motors per established standards
- Identified types of single phase transformers as per established standards
- performed calculations involving single AC and DC transformers as per established standards
- Identified types of single phase generators as per established standards
- Identified Motor starting methods as per established procedure
- Established DC motor speed control as per standard operating procedures

3.2.3.5 Self-Assessment

2. What is s shunt field regulator in speed control of DC motor

.

3. Name and explain two types of a DC generator.

4. Determine the terminal voltage of a generator which develops an e.m.f. of 200V and has an armature current of 30A on load. Assume the armature resistance is 0.30 , terminal voltage,

4. Name types of a DC motors

5. A 240V shunt motor takes a total current of 30A. If the field winding resistance Rf = 150_ and the armature resistance Ra = 0.4_, determine (a) the current in the armature and (b) the back e.m.f.= 28.4A

3.2.3.6. Tools, Equipment, Supplies and Materials

- Scientific calculators
- Motor
- Generator
- Transformer

3.2.3.7 References

John Bird(2017) Electrical and Electronics Principles Technology fifth Edition o John Bird(2017) Electrical and Electronics Principles Technology sixth Edition

o Watkins, A.J, Kitcher C (2009) Electrical Installation calculations Basic Eighth Elsevier Ltd

o Linsley, T, (2011), Basic Electrical Installation Work Sixth Edition

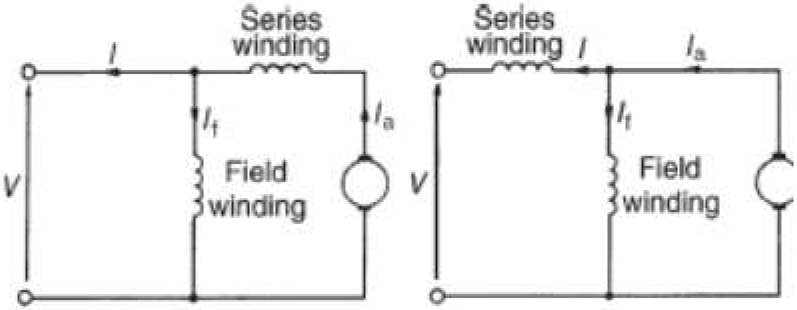
o Kitcher, K,(2008) Practical Guide to Inspection, Testing and Certification of Electrical Installations First Edition Elsevier Ltd

3.2.3.8 Response To Self-Assessment

2. The speed is varied either by varying the value of flux, , or by varying the value of Ra. The former is achieved by using a variable resistor in series with the field winding, such a resistor is called the shunt field regulator

3. **([a) Compound-wound generators**

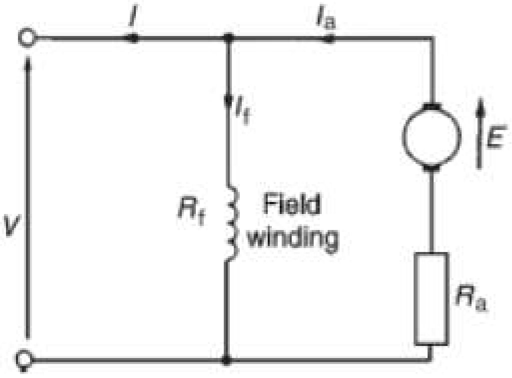
In the compound-wound generator two methods of connection are used, both having a mixture of shunt and series windings, designed to combine the advantages of each.(a) shows what is termed a long shunt compound generator,(b) shows short-shunt compound generator. The latter is the most generally used form of d.c. generator



(a) (b)

. (b) Shunt-wound generator

In a shunt-wound generator the field winding is connected in parallel with the armature. The field winding has a relatively high resistance and therefore the current carried is only a fraction of the armature current.



4. Determine the terminal voltage of a generator which develops an e.m.f. of 200V and has an armature current of 30A on load. Assume the armature resistance is 0.30 , terminal voltage,

V = E − Ia Ra

= 200−(30)(0.30)

= 200−9 = 191volts.

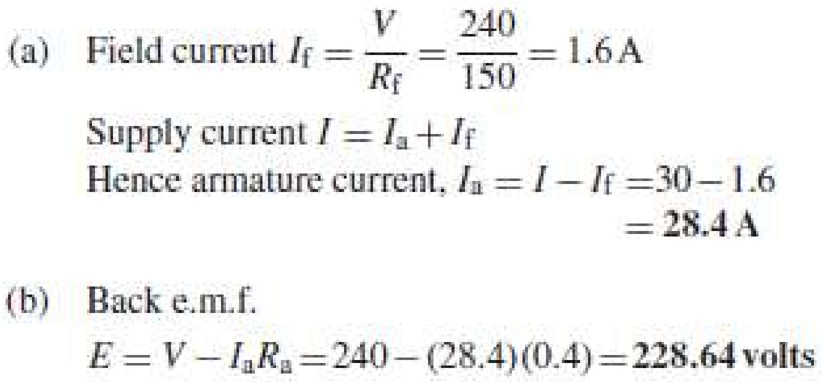
4. Types of DC motors

i. Shunt-wound motor

ii. Series-wound motor

iii. Compound-wound motor

5. A 240V shunt motor takes a total current of 30A. If the field winding resistance Rf = 150_ and the armature resistance Ra = 0.4_, determine (a) the current in the armature and (b) the back e.m.f.= 28.4A



(a) Field current $I_f = \frac{V}{R_f} = \frac{240}{150} = 1.6\,\text{A}$

Supply current $I = I_a + I_f$

Hence armature current, $I_a = I - I_f = 30 - 1.6$

$= \mathbf{28.4\,A}$

(b) Back e.m.f.

$E = V - I_a R_a = 240 - (28.4)(0.4) = \mathbf{228.64\ volts}$

3.2.4 Learning Outcome 4: Earthing in Electrical Installations

3.2.4.1 Introduction to the learning outcome

To apply earthing in Electrical Installations trainee is required to understand

Meaning of earthing, Terms in earthing, earthing systems, earthing points in electrical installation, IEE regulations and Factors to consider in selecting an earthing system

3.2.4.2 Performance Standard

- Earthing types are identified as per established standards
- Earthing systems are identified as per established procedures
- Tests to determine the earthing system are performed as per established standards
- Test on an earthing system is performed in line with the IEE regulations

3.2.4.3 Information Sheet

Earthed Systems

Definition of terms

- Static Charge: The electricity generated when two dissimilar substances come into contact. Conveyer belts are active producers of static electricity.
- Switching Surge: A transient wave of voltage in an electric circuit caused by the operation of a switching device interrupting load current or fault current.
- Transient Overvoltage: The temporary overvoltage of short duration associated with the operation of the switching device, a fault, a lightning stroke, or during arcing earth faults on the unearthed system.
- System: An earthed system consists of all interconnected earthing connections in a specific power system and is defined by its isolation from adjacent earthing systems. The isolation is provided by transformers primary and secondary windings that are coupled only by magnetic means. Thus, the system boundary is defined by the lack of a physical connection that is either metallic or through a significantly high impedance. The limits and boundaries of earthing systems

In the earthed systems, at least one conductor or point (usually the middle wire or neutral point of generators or transformers) is intentionally earthed, either solidly or through an impedance. The earthed systems have multiple advantages:

- Greater safety;
- No excessive system over voltages that can occur on unearthed systems during arcing, resonant, or near - resonant earth faults; and
- Easier detection and location of faults when they occur.

Purpose of System Earthing

System earthing or intentional connection of a phase or neutral conductor to earth is for the purpose of controlling the voltage to earth within predictable limits. It also provides for a flow of current that will allow detection of an undesired connection between the system conductors and the earth, and which may initiate the operation of automatic devices to remove the source of voltage from conductors with such undesired connections to earth. The American NEC prescribes certain system earthing connections that must be made to be in compliance with the code. The control of voltage to earth limits the voltage stress on the insulation of conductors so that insulation performance can be predicted more readily. The control of voltage also allows for the reduction of shock hazard to any living body who might come in contact with the live conductors.

Methods of System Neutral Earthing

The earthing of the system can be done by either solid earthing or earthing through an impedance (reactive or resistive or earth - fault neutralizer)

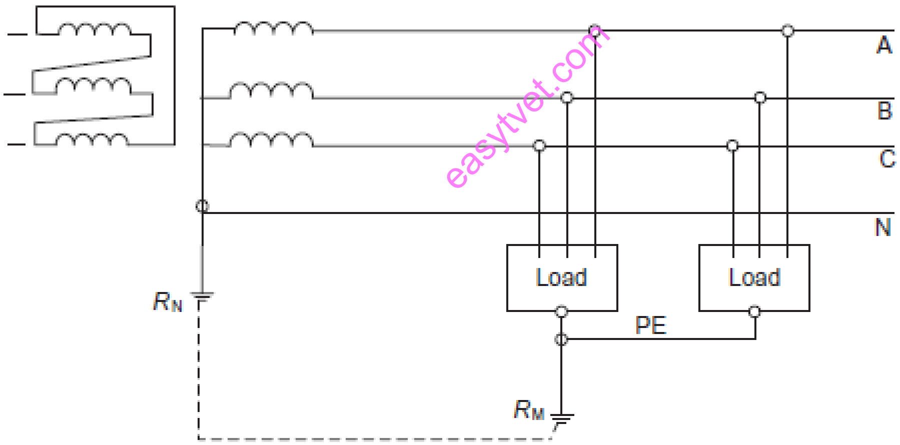
Solid Earthed: The neutral point is connected directly through an adequate earth connection in which no impedance is intentionally inserted. The direct neutral earthing is either distributed or non-distributed.

Reactance Earthed: The neutral point is earthed through impedance, the principle element of which is an inductive reactance.

TT Earthing System

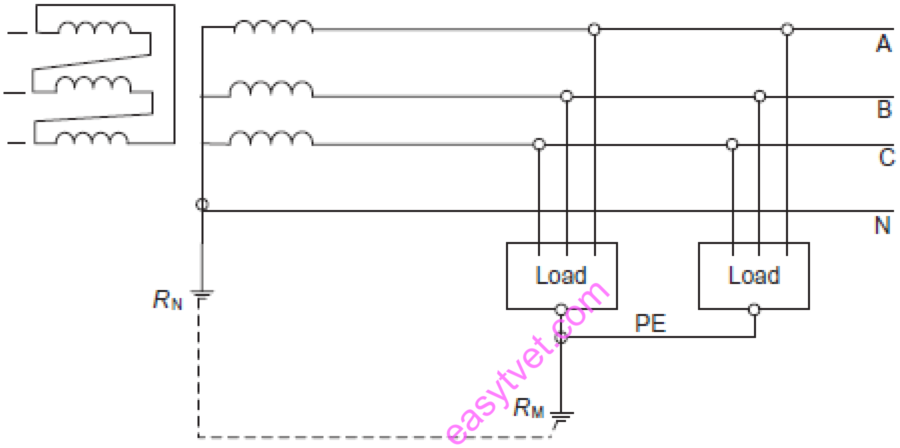
In this system, the neutral is directly earthed as it is denoted by the first letter“ T ” and the exposed conductive parts of the loads are directly earthed via a conductor of PE individually or altogether as it is denoted by the second letter “ T ”

The earth of both neutral conductor and protective conductor may or may not be interconnected or combined. On the other hand, all exposed conductive parts protected by the same protective device should be connected to the same earth.



TN Earthing System

This system has directly earthed neutral, which is denoted by the first letter“ T ” while the exposed conductive parts of the loads are connected via a PE conductor to the neutral conductor.



3.2.4.4 Learning Activities

- Identified earthing types as per established standards
- Identified earthing systems identified as per established procedures
- Identified tests to determine the earthing system performed as per established standards

- Performed test on an earthing system in line with the IEE regulations

3.2.4.5 Self-Assessment

1. What is a system
2. State three advantages of earthed system
3. Name methods of system neutral earthing
4. What is TN earthed

3.2.4.6 Tools, Equipment, Supplies and Materials

Electrical installation tool kit

Multimeter/AVO meter

Wattmeter

Insulation resistance tester

Clamp meter

3.2.4.7 References

o John Bird (2017) Electrical and Electronics Principles Technology fifth Edition

- John Bird (2017) Electrical and Electronics Principles Technology sixth Edition
- Kitcher, K, (2008) Practical Guide to Inspection, Testing and Certification of Electrical Installations First Edition Elsevier Ltd

3.2.4.8 Response To Self-Assessment

1. System: An earthed system consists of all interconnected earthing connections in a specific power system and is defined by its isolation from adjacent earthing systems. The isolation is provided by transformers primary and secondary windings that are coupled only by magnetic means. Thus, the system boundary is defined by the lack of a physical connection that is either metallic or through a significantly high impedance. The limits and boundaries of earthing systems

2.

Greater safety.

•No excessive system over voltages that can occur on unearthed systems during arcing, resonant, or near - resonant earth faults

•Easier detection and location of faults when they occur.

3.

- Solid Earthed
- Reactance Earthed

4. This system has directly earthed neutral, which is denoted by the first letter "T " while the exposed conductive parts of the loads are connected via a PE conductor to the neutral conductor.

3.2.5 Learning Outcome 5: Capacitance and Inductance

3.2.5.1 Introduction to the learning outcome

To apply capacitance and inductance one is required to understand; Meaning of electrostatic field, Sources of electrostatic field, Electric field strength and capacitance, Electric flux density, Permittivity, Types capacitors, Magnetic circuits and Magnetic fields.

3.2.5.2 Performance Standard

- Sources of Electrostatic fields are identified as established procedures
- Dielectric materials are identified as per the established standards
- Calculations involving capacitor parameters are performed as per established standards
- Types of capacitors are identified as per established standards
- Concept of charge and electrostatic field is established as per established standards
- Calculations involving capacitors are performed as per established standards
- Concept of magnetic circuits is identified as per established procedure

Parameters

- Calculations involving inductors are performed as per the established procedures

3.2.5.3 Information Sheet

Electrostatic field

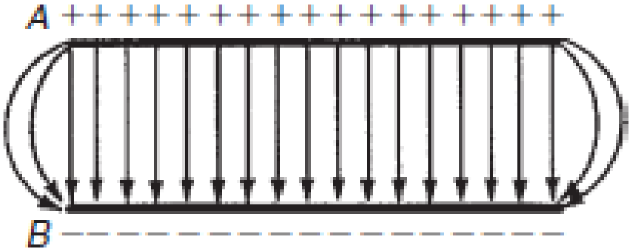
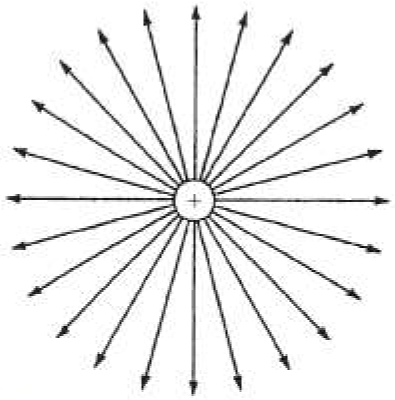
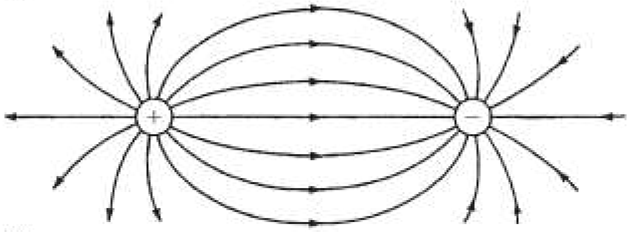


Fig. above represents two parallel metal plates, A and B, charged to different potentials. If an electron that has a negative charge is placed between the plates, a force will act on the electron tending to push it away from the negative plate B towards the positive plate, A. Similarly, a positive charge would be acted on by a force tending to move it towards the negative plate. Any region such as that shown between the plates in Fig. above, in which an electric charge experiences a force, is called an electrostatic field. The direction of the field is defined as that of the force acting on a positive charge placed in the field. the direction of the force is from the positive plate to the negative plate. Such a field may be represented in magnitude and direction by lines of electric force drawn between the charged surfaces. The closeness of the lines is an indication of the field strength. Whenever a p.d. is established between two points, an electric field will always exist.



(a)



(b)

Fig(a) above shows a typical field pattern for an isolated point charge, and Fig(b) shows the field pattern for adjacent charges of opposite polarity. Electric lines of force (often called electric flux lines) are continuous and start and finish on point charges; also, the lines cannot cross each other. When a charged body is placed close to an uncharged body, an induced charge of opposite sign appears on the surface of the uncharged body. This is because lines of force from the charged body terminate on its surface.

The concept of field lines or lines of force is used to illustrate the properties of an electric field. However,

it should be remembered that they are only aids to the imagination.

The force of attraction or repulsion between two electrically charged bodies is proportional to the magnitude of their charges and inversely proportional to the square of the distance separating them, i.e.

force $\propto q1q2/d2$

Capacitors

Every system of electrical conductors possesses capacitance. For example, there is capacitance between the conductors of overhead transmission lines and also between the wires of a telephone cable. In these examples the capacitance is undesirable but has to be accepted, minimized or compensated for. There are other situations where capacitance is a desirable property.

Devices specially constructed to possess capacitance are called capacitors (or condensers, as they used to be called). In its simplest form a capacitor consists of two plates which are separated by an insulating material known as a dielectric. A capacitor has the ability to store a quantity of static electricity.

The symbols for a fixed capacitor and a variable capacitor used in electrical circuit diagrams are shown below

The ***charge Q*** stored in a capacitor is given by:

$Q = I \times t$ ***coulombs***

where I is the current in amperes and t the time in seconds.


Fixed capacitor


Variable capacitor

(a) $C = 4\,\mu\text{F} = 4 \times 10^{-6}\,\text{F}$ and
$Q = 5\,\text{mC} = 5 \times 10^{-3}\,\text{C}$

$$\text{Since } C = \frac{Q}{V} \text{ then } V = \frac{Q}{C} = \frac{5 \times 10^{-3}}{4 \times 10^{-6}}$$

$$= \frac{5 \times 10^{6}}{4 \times 10^{3}} = \frac{5000}{4}$$

Hence p.d. $V = 1250\,\text{V}$ or $1.25\,\text{kV}$

(b) $C = 50\,\text{pF} = 50 \times 10^{-12}\,\text{F}$ and

$V = 2\,\text{kV} = 2000\,\text{V}$

$$Q = CV = 50 \times 10^{-12} \times 2000$$

$$= \frac{5 \times 2}{10^{8}} = 0.1 \times 10^{-6}$$

Hence, charge $Q = 0.1\,\mu\text{C}$

Example

(a) Determine the p.d. across a 4Mf capacitor when charged with 5mC. (b) Find the charge on a 50 pF capacitor when the voltage applied to it is 2kV

Dielectric material

For a parallel plate capacitor, as shown below. experiments show that capacitance C is proportional to

the area A of a plate, inversely proportional to the plate spacing d (i.e., the dielectric thickness) and depends on the nature of the dielectric:

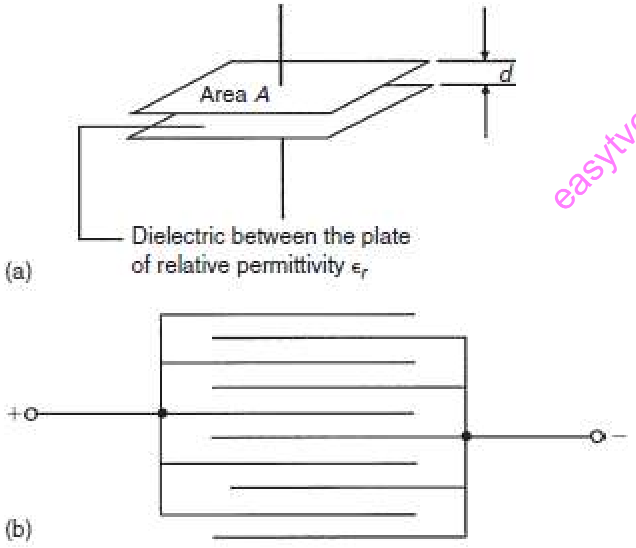
Capacitance, $C = \frac{\varepsilon_0 \varepsilon_r A}{d}$ **farads**

Where $\varepsilon_0 = 8.85\times10^{-12}$ F/m (constant)

ε_r = relative permittivity

A = area of one of the plates, in m^2, and

d = thickness of dielectric in m



Another method used to increase the capacitance is to interleave several plates as shown in Fig.(b).

Ten plates are shown, forming nine capacitors with a capacitance nine times that of one pair of plates.

If such an arrangement has n plates then capacitance C ∝ (n−1). Thus capacitance

$$C = \frac{\varepsilon_0 \varepsilon_r A(n-1)}{d} \text{ farads}$$

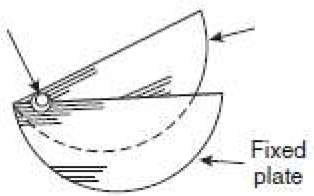
The maximum amount of field strength that a dielectric can withstand is called the dielectric strength of the material. Dielectric strength,

$$E_m = \frac{V_m}{d}$$

Types of Capacitors

1. Variable air capacitors. These usually consist of two sets of metal plates (such as aluminium), one

fixed, the other variable. The set of moving plates rotate on a spindle as shown by the end view of

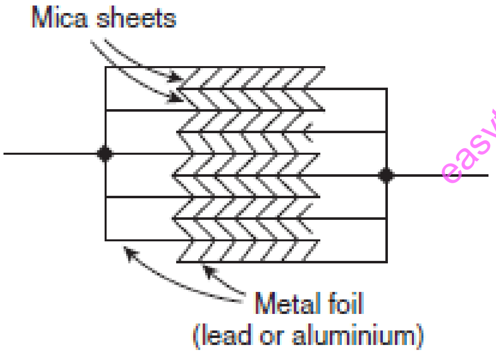


As the moving plates are rotated through half a revolution, the meshing, and therefore the capacitance,

Varies from a minimum to a maximum value. Variable air capacitors are used in radio and electronic circuits where very low losses are required, or where a variable capacitance is needed. The maximum

Value of such capacitors is between 500Pf and 1000pF.

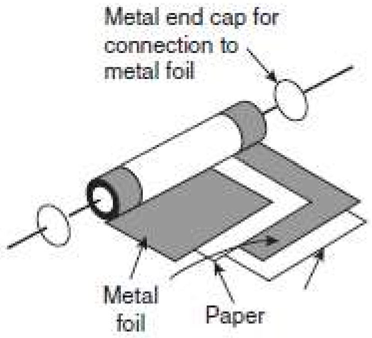
2. Mica capacitors. A typical older type construction is shown below



Usually, the whole capacitor is impregnated with wax and placed in a Bakelite case. Mica is easily

obtained in thin sheets and is a good insulator. However, mica is expensive and is not used in capacitors above about 0.2μF. A modified form of mica capacitor is the silvered mica type. The mica is coated on both sides with a thin layer of silver which forms the plates. Capacitance is stable and less likely to change with age. Such capacitors have a constant capacitance with change of temperature, a high working voltage rating and along service life and are used in high frequency circuits with fixed values of capacitance up to about 1000pF.

3. Paper capacitors. A typical paper capacitor is shown in Fig. below where the length of the roll Corresponds to the capacitance required.



The whole is usually impregnated with oil or wax to exclude moisture, and then placed in a plastic or aluminium container for protection. Paper capacitors are made in various working voltages up to about 150kV and are used where loss is not very important. The maximum value of this type of capacitor is between 500pF and 10μF.Disadvantages of paper capacitors include variation in capacitance with temperature change and a shorter service life than most other types of capacitor

5. Plastic capacitors. Some plastic materials such as polystyrene and Teflon can be used as dielectrics.

Construction is similar to the paper capacitor, but using a plastic film instead of paper. Plastic capacitors operate well under conditions of high temperature, provide a precise value of capacitance,

a very long service life and high reliability

6. Titanium oxide capacitors have a very high capacitance with a small physical size when used at a low temperature.

7. Electrolytic capacitors. Construction is similar to the paper capacitor, with aluminium foil used for the

Plates and with a thick absorbent material, such as paper, impregnated with an electrolyte (ammonium

borate) separating the plates. The finished capacitor is usually assembled in an aluminium container

and hermetically sealed. Its operation depends on the formation of a thin aluminium oxide layer on the

positive plate by electrolytic action when a suitable direct potential is maintained between the plates.

This oxide layer is very thin and forms the dielectric. (The absorbent paper between the plates is a

conductor and does not act as a dielectric.) Such capacitors must always be used on d.c. and must

be connected with the correct polarity; if this is not done the capacitor will be destroyed since the oxide layer will be destroyed. Electrolytic capacitors are manufactured with working voltage from 6V to 600V, although accuracy is generally not very high. These capacitors possess a much larger capacitance than other types of capacitors of similar dimensions due to the oxide film being only a few microns thick.

The fact that they can be used only on d.c. supplies limit their usefulness.

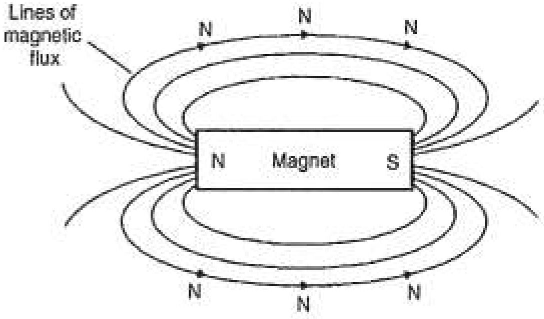
MAGNETIC CIRCUIT

Magnetic field

A permanent magnet is a piece of ferromagnetic material (such as iron, nickel or cobalt) which has properties of attracting other pieces of these materials. A permanent magnet will position itself in a north and south direction when freely suspended. The north-seeking end of the magnet is called the North Pole, N, and the south-seeking end the South Pole, the area around a magnet is called the magnetic field and it is in this area that the effects of the magnetic force produced by the magnet can be detected.

A magnetic field cannot be seen, felt, smelt or heard and therefore is difficult to represent. Michael Faraday suggested that the magnetic field could be represented pictorially, by imagining the field to consist of lines of magnetic flux, which enables investigation of the distribution and density of the field to be carried out.

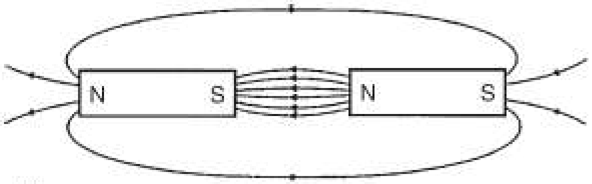
The distribution of a magnetic field can be investigated by using some iron filings. A bar magnet is placed on a flat surface covered by, say, cardboard, upon which is sprinkled some iron filings. If the cardboard is gently tapped the filings will assume a pattern similar to that shown below. If a number of magnets of different strength are used, it is found that the stronger the field the



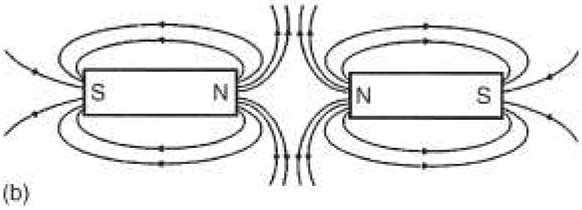
Closer are the lines of magnetic flux and vice versa. Thus, a magnetic field has the property of exerting a force, demonstrated in this case by causing the iron filings to move into the pattern shown. The strength of the magnetic field decreases as we move away from the magnet. It should be realized, of course, that the magnetic field is three-dimensional in its effect, and not acting in one plane as appears to be the case in this experiment. If a compass is placed in the magnetic field in various positions, the direction of the lines of flux may be determined by noting the direction of the compass pointer.

The direction of a magnetic field at any point is taken as that in which the north-seeking pole of a compass needle points when suspended in the field. The direction of a line of flux is from the north pole to the south pole on the outside of the magnet and is then assumed to continue through the magnet back to the point at which it emerged at the north pole. Thus, such lines of flux always form complete closed loops or paths, they never intersect and always have a definite direction.

The laws of magnetic attraction and repulsion can be demonstrated by using two bar magnets. In fig. below with unlike poles adjacent, attraction takes place



(a)



(b)

Lines of flux are imagined to contract and the magnets try to pull together. The magnetic field is strongest in between the two magnets, shown by the lines of flux being close together. In Fig (b), with similar poles adjacent (i.e. two north poles), repulsion occurs, i.e. the two north poles try to push each other apart, since magnetic flux lines running side by side in the same direction repel.

7.3 Magnetic

Magnetic Flux and flux density

Magnetic flux is the amount of magnetic field (or the number of lines of force) produced by magnetic source. The symbol for magnetic flux is Φ

The unit of magnetic flux is the weber∗, Wb.

Magnetic flux density is the amount of flux passing through a defined area that is perpendicular to the direction of the flux:

Magnetic flux density = magnetic flux

area

The symbol for magnetic flux density is B. The unit of magnetic flux density is the tesla∗, where

1 T = 1Wb/m2. Hence B = Φ/A tesla where A(m2) is the area

Magnetomotive Force and Magnetic Field Strength

Magnetomotive force (m.m.f.) is the cause of the existence of a magnetic flux in a magnetic circuit, m.m.f. Fm = NI amperes where N is the number of conductors (or turns) and I is the current in amperes. The unit of m.m.f is sometimes expressed as 'ampere-turns'. However, since 'turns 'have no dimensions, the SI unit of m.m.f. is the ampere.

Magnetic field strength (or magnetizing force),

H = NI/l ampere per metre where l is the mean length of the flux path in metres.

Thus m.m.f. = NI = Hl amperes

Inductors

A component called an inductor is used when the property of inductance is required in a circuit. The basic form of an inductor is simply a coil of wire. Factors which affect the inductance of an inductor include:

(i) The number of turns of wire – the more turns the higher the inductance

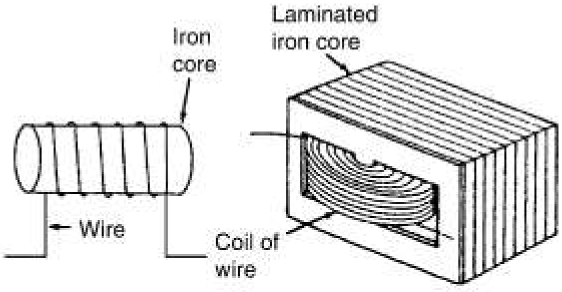
(ii) The cross-sectional area of the coil of wire – the greater the cross-sectional area the higher the inductance

(iii) The presence of a magnetic core – when the coil is wound on an iron core the same current sets up a more concentrated magnetic field and the inductance is increased

(iv) The way the turns are arranged – a short, thick coil of wire has a higher inductance than a long, thin one.

Two examples of practical inductors are shown below and the standard electrical circuit diagram

Symbols for air-cored and iron-cored inductors.

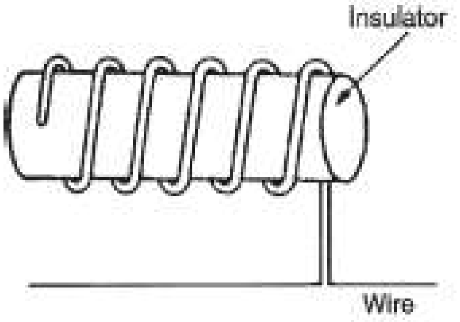


(a) (b)

Air-cored inductor

Iron-cored inductor

An iron-cored inductor is often called a choke since, when used in a.c. circuits, it has a choking effect, limiting the current flowing through it.Inductance is often undesirable in a circuit. To reduce inductance to a minimum the wire may be bent back on itself, as shown below, so that the magnetizing effect of one conductor is neutralized by that of the adjacent conductor. The wire may be coiled around an insulator, as shown, without increasing the inductance. Standard resistors may be non-inductively wound in this manner.



Example

A flux of 25mWb links with a1500 turn coil when a current of 3A passes through the coil. Calculate

(a) The inductance of the coil,

(b) The energy stored in the magnetic field and

(c) The average e.m.f. induced if the current falls to zero in 150ms.

(a) **Inductance,**

$$L = \frac{N\Phi}{I} = \frac{(1500)(25 \times 10^{-3})}{3} = \mathbf{12.5\,H}$$

(b) **Energy stored,**

$$W = \frac{1}{2}LI^2 = \frac{1}{2}(12.5)(3)^2 = \mathbf{56.25\,J}$$

(c) **Induced e.m.f.,**

$$E = -L\frac{dI}{dt} = -(12.5)\left(\frac{3-0}{150 \times 10^{-3}}\right)$$

$$= \mathbf{-250\,V}$$

(Alternatively,

$$E = -N\frac{d\Phi}{dt}$$

$$= -(1500)\left(\frac{25 \times 10^{-3}}{150 \times 10^{-3}}\right)$$

$$= \mathbf{-250\,V}$$

since if the current falls to zero so does the flux.)

3.2.5.4 Learning Activities

1. Identified sources of Electrostatic fields as established procedures
2. identified dielectric materials as per the established standards
3. performed calculations involving capacitor parameters as per established standards
4. identified types of capacitors as per established standards
5. established concept of charge and electrostatic field as per established standards
6. performed Calculations involving capacitors as per established standards
7. identified concept of magnetic circuits as per established procedure

Parameters

- performed calculations involving inductors as per established procedures.

1.2.5.5 Self-Assessment

1. what is a capacitor
2. Draw the symbols of fixed and variable capacitors
3. Differentiate between magnetic flux and magnetic flux density
4. What are the factors affecting inductance of an inductor?
5. Name five types of a capacitor

1.2.5.6 Tools, Equipment, Supplies and Materials

- Scientific calculator
- Capacitor
- Dielectric materials
- Inductor
- magnets

1.2.5.7 References

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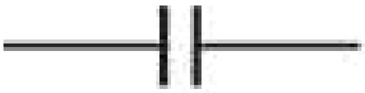
3.2.5.8 Response To Self-Assessment

1. Devices specially constructed to possess capacitance are called capacitors (or condensers, as they used to be called). In its simplest form a capacitor consists of two plates which are separated by an insulating material known as a dielectric. A capacitor has the ability to store a quantity of static electricity.

2.


Fixed capacitor


Variable capacitor

3. Magnetic flux is the amount of magnetic field (or the number of lines of force) produced by magnetic source. The symbol for magnetic flux is Φ

The unit of magnetic flux is the weber∗, Wb.

Magnetic flux density is the amount of flux passing through a defined area that is perpendicular to the direction of the flux:

Magnetic flux density = magnetic flux

Area

The symbol for magnetic flux density is B. The unit of magnetic flux density is the tesla∗, T, where

1 T = 1Wb/m2. Hence

B = Φ/A tesla where A (m2) is the area

4.

- (i) The number of turns of wire – the more turns the higher the inductance
- (ii) The cross-sectional area of the coil of wire – the greater the cross-sectional area the higher the inductance

(iii) The presence of a magnetic core – when the coil is wound on an iron core the same current sets up a more concentrated magnetic field and the inductance is increased

(iv) The way the turns are arranged – a short, thick coil of wire has a higher inductance than a long, thin one.

5. Types of capacitors

- Variable air capacitor
- Mica capacitor
- Paper capacitor
- Plastic capacitor
- Ceramic capacitor